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PROJECTILE ENGRAVING MUTATIONS AND THEIR RELATIONSHIPS TO ACCURACY OF THE M1CA1 RIFLE

Ronald E. Elbe, et al

Rock Island Arsenal
Rock Island, Illinois

June 1975

PROJECTILE ENGRAVING MUTATIONS AND THEIR RELATIONSHIPS TO ACCURACY OF THE M16A1 RIFLE

BY

RONALD E. ELBE

AND

BERNARD C. KNOUSE

JUNE 1975

SMALL ARMS WEAPONS SYSTEMS DIRECTORATE

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ROCK ISLAND ARSENAL
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A two-phase test program was conducted in order to evaluate the hypothesis that changes in the accuracy of a rifle are reflected in changes of the engraving patterns found on projectiles fired from that rifle. Three mutations of projectile engraving characteristics were isolated. These mutations were: (1) widening of the grooves engraved in the projectiles; (2) increasing variation in the lengths of the grooves on a bullet; (3) the appearance of surface mutilation on the bullet jackets. Each of the mutations demonstrated some correlation with accuracy. The widening of the grooves correlated best with

Block 20 ABSTRACT (continued)

accuracy, exhibiting a correlation coefficient above .7 over a wide range of firing rates, ammunition types, and barrel manufacturing processes.

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ABSTRACT

A two-phase test program was conducted in order to evaluate the hypothesis that changes in the accuracy of a rifle are reflected in changes of the engraving patterns found on projectiles fired from that rifle. Three mutations of projectile engraving characteristics were isolated. These mutations were: (1) widening of the grooves engraved in the projectiles; (2) increasing variation in the lengths of the grooves on a bullet; (3) the appearance of surface mutilation on the bullet jackets. Each of the mutations demonstrated some correlation with accuracy. The widening of the grooves correlated best with accuracy, exhibiting a correlation coefficient above .7 over a wide range of firing rates, ammunition types, and barrel manufacturing processes.

FOREWORD

The efforts of many here at Rock Island Arsenal were enlisted during the course of this program. The following organizations and individuals were essential and their support and cooperation are hereby recognized:

Weapons Test Division	SARRI-LE-T
Metrology Laboratory	SARRI-QM
Miss Luanne Beinke	SARRI-LS-P
Mr. Loren Brunton	SARRI-LS-P
Mr. Howard Leedham	SARRI-LS-P
Mrs. Vicki Myers	SARRI-LS-P

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BACKGROUND

As a weapon is fired, its bore surface erodes. This erosion eventually leads to unsatisfactory accuracy, muzzle velocity, and projectile yaw. Extensive testing has demonstrated that for rifles, accuracy becomes unacceptable before velocity and yaw do. Thus, accuracy is the parameter which limits the service life of the M16A1 Rifle. Unfortunately, the determination of a rifle's accuracy requires range facilities, trained shooters, ammunition expenditure and much time. These requirements have led the Army to conclude that it is not practical to directly test the accuracy of rifles in the field on a routine, periodic basis.

Because erosion of the bore is generally considered to be a principal cause of accuracy loss, and because measurement of erosion is relatively simple, it is only natural that erosion should be substituted for accuracy as a field rejection criteria. Under this philosophy, breech erosion gages have been developed and fielded for both the M14 and M16A1 Rifles However, testing of the M16A1 Rifle has proven that the correlation between erosion and accuracy is poor. The depth of penetration of an erosion gage is not a good indicator of the accuracy of an M16A1 Rifle. Consequently, a search was initiated for a practical means for determining the accuracy of rifles in the field. This report reviews the initial stage of that search.

OBJECTIVE

It was hypothesized that the change in accuracy of a barrel as it wears out should be reflected in visible changes on the projectiles fired by that weapon. To restate the hypothesis, if all external parameters remain constant, the physical interface between the projectile and the barrel's bore dictates the projectile's trajectory, and the changes in this physical interface which degrade accuracy should be reflected in the bore's engraving on the projectiles.

The objective of this program was to determine the validity of the hypothesis by determining:

(1) whether mutations occur in projectile engraving characteristics as a barrel wears;

(2) if mutations do occur, whether they can be correlated to changes in accuracy.

SCOPE OF PROGRAM

All test data were gathered by employing two previously programmed tests. In the first of these tests, twenty-thousand rounds of M193 Ball ammunition were fired through each of nine M16A1 rifles at a nominal rate of twenty rounds per minute. Each of these weapons contained a standard replacement barrel and front sight assembly from one of three contractors who have fabricated replacement barrel assemblies for the M16A1. Three ten-shot targets were fired from each weapon at 1000 round intervals throughout the test. Three projectiles from each weapon were trapped in foam at 5,000 round intervals throughout the test. The projectiles trapped in the foam are assumed to exhibit engraving characteristics typical of projectiles fired from the same barrel in the accuracy firings at the same stage of the test. Since the foam was not available until after the test's initiation, the first projectiles trapped in it were at the 5000 round stage of the test.

The trapped projectiles were examined under 10X magnification and three types of mutation were isolated. Each of these mutations was quantified and correlation coefficients between the mutation and accuracy were calculated. Two mutations showed some promise o correlating well with accuracy. Therefore, it was decided to study those two mutations during the second test.

The second, much more extensive test was used to determine the correlation between accuracy and each mutation over a broad range of ammunition types, rates of fire, and barrel manufacturing processes.

During this second test, twenty-seven chrome-plated M16A1 Rifle barrels were fired a total of approximately 500,000 rounds at rates of fire of 20, 60, and 100 rounds per minute. Nine standard replacement barrel assemblies from each of the three producers of chrome-plated replacement barrel assemblies were assembled to rifles for this test. Each of the three manufacturers used a unique process to produce his barrels. Consequently three distinctly different bore configurations, all meeting the requirements of the production technical data package, were utilized in the test. This allowed a study of the effects of differences in processing on bullet mutation to be included in this report. Three barrels from each manufacturer were fired at each rate, with two of the barrels firing M193 ball ammunition and one barrel firing M196 tracer ammunition. Accuracy firings and projectile trapping were conducted at appropriate intervals throughout the test. Again, analysis of the projectiles was conducted at 10X magnification and correlations between accuracy and engraving mutation were calculated.

DESCRIPTION OF TEST ITEMS

The barrels manufactured by Process "A" were rifled by rotary swaging. The bores displayed good surface finish and chrome adhesion. Land height was relatively low and the land edges were significantly more rounded than those on the other barrels (see Figure 11, Appendix B).

The barrels manufactured by Process "B" were rifled by button swaging. These bores displayed good land edge definition and good chrome adhesion, but relatively rougher surface finish than the other barrels (see Figure 12, Appendix B).

The barrels manufactured by Process "C" were rifled by rotary swaging. The lands of these bores were not symmetrical. The leading edge of each land showed good definition while the trailing edge was much more rounded (see Figure 13, Appendix B). Chrome adhesion was not as good on these barrels as on the others. However, surface finish on the chrome was better than that of Process "B", although not as good as that of Process "A".

This qualitative evaluation of surface finish and chrome adhesion was conducted using a 60X borescope whose output was displayed on a closed circuit television screen.

Approximately 20 one-foot-thick blocks of polyurethane foam (2 ft x 2 ft) were used to trap the bullets. The specifications of the foam are as follows:

Density - 1.45 to 1.55 lb. per cu ft.
Elongation - 200% minimum
Tensile - 10 lb. per sq. in.
ILD - 26 to 31 lb.
Tear - 2 lb. per in.

Analysis of the projectile engraving was conducted at 10X. At that magnification the graduations on the microscope's scale were .005 inches apart. Visual interpolation was used to approximate engraving dimension to the nearest .001 inch.

SUMMARY OF RESULTS OF TEST I

Examination of the projectiles trapped during the first test revealed three obvious engraving mutations. One of these mutations is a widening of the grooves engraved in the projectiles fired from the weapons of Processes "A" and "C" as the weapons reach the end of their accuracy life. Each entry in Table II, Column 4 in Appendix A represents the average land impression width of three projectiles (average width of all six grooves in each of three projectiles). Examples of these land impression widths and their variations are shown in Figures 1 through 4 and Figure 6 of Appendix B. The arrowheads denote approximately the edges of a groove in the projectile.

Another mutation noted is an increase in the difference in the lengths of the longest and shortest grooves in a given projectile. This variation in groove length increases with weapon wear in nearly all test weapons; but it is most pronounced in Process "A" weapons. Colliomn 5 of Table II in Appendix A quantitatively displays this mutation. Each entry in Table II is the average of the differences between the longest and shortest land impression lengths on each of three projectiles. Figures 9 and 10 of Appendix B show an example of this variation.

The third mutation is the appearance of gouges, nicks, scrapes, tears, and general surface roughness on some projectiles fired from Process "B" weapons. This mutation was found on five of the six projectiles fired from the two rifles of Process "B" which were inaccurate at the 20,000 round stage of the test. Column 6 of Table I records the occurrence of jacket mutilations. Figure 5 in Appendix B shows a typical example of this jacket mutilation.

Results of the accuracy firings at 5000 round intervals are given in Column 7 of Table II of Appendix A. Each entry in the table represents the average of the extreme spreads of three ten-shot targets fired from one rifle.

No projectile yaw was noted on any of the targets fired.

Velocity losses were small. Average velocities recorded at test conclusion were less than average velocities at test initiation by the following percentages: 2.1% for Process "A", 2.2% for Process "B", and 0.9% for Process "C".

ANALYSIS OF RESULTS OF TEST I

The graphing of the data and the calculation of associated correlation coefficients are relatively straightforward. Graph 1 of Appendix C shows strong linear relationships between land impression width and extreme spread for weapons of Process "A" and for all weapons (correlation coefficients of .90 and .73 respectively). Although weapons of Process "B" and "C" did not show the linear relationship (correlation coefficients of .20 and .38 respectively), this may well have been due to the limitations of the data. For instance, the extreme spread of Process "C" weapons never became large enough to determine whether a correlation would exist.

Graph 2 in Appendix C shows good correlations between longest-minus-shortest land impressions length and extreme spread for weapons of Processes "A" and "B", and for all weapons (correlation coefficients of .57, .82, and .66 respectively). Once again, the limitations of the data prevent a relationship from being found for Process "C" weapons.

The third mutation, jacket mutilation, is perhaps best studied by merely reviewing Appendix A and noting that at the tests' conclusion, the only two weapons causing jacket mutilation were the two inaccurate Process "B" weapons.

SUMMARY OF RESULTS OF TEST II

The widths and lengths of all six grooves were measured on more than 500 projectiles. During the measurements, each projectile was checked for jacket mutilation. When combined with the accuracy data, these observations formed the data base from Test II which is recorded in Table III of Appendix A. The entries in Table III are directly analogous to their counterparts in Table II. For example, each entry in the extreme spread column again represents the average extreme spread of three 10-shot targets. As in Test I, no projectile yaws were noted and velocity losses were small during Test II.

ANALYSIS OF RESULTS OF TEST II

The data from Test II were analyzed in an attempt to answer five pertinent questions concerning projectile mutation. These questions are:

(1) With a larger data base than than available in Test I, how well does each mutation correlate with accuracy?

(2) Is the correlation between accuracy and each mutation dependent upon barrel manufacturing process?

(3) Is the correlation between accuracy and each mutation dependent upon rate of fire?

(4) Is the correlation between accuracy and each mutation dependent upon type of ammunition fired?

(5) If each mutation were used as a measure of accuracy in the field, what cut-off point in the mutation would correspond to the field accuracy rejection criteria of seven inches extreme spread at 100 yards?

Graphs 3 through 11 display the relationship between land impression width and extreme spread for various portions of the data from Test II. Graphs 12 through 20 similarly display the relationship between longest-shortest land and extreme spread.

Note that all graphs in Appendix C have linear and second order regression lines plotted over the data. The information pertinent to this analysis has been summarized in the following Table I.

The first two columns of Table I are self-explanatory. The third column lists the correlation coefficients for the data on the graphs. The fourth column lists the land impression width which corresponds to seven inches extreme spread on the second order regression line. The last column is similar to the preceding one except that longest-shortest land impression rather than land impression width is portrayed.

Data from Table I can be utilized to answer the five questions posed at the beginning of this section.

TABLE I

GRAPH NUMBER	GRAPH TITLE	CORRELATION COEFF.	LAND IMP. WIDTH CUTOFF*	LONG-SHORT IMP. CUTOFF*
1	20 RDS PER MIN, ALL PROCESSES, BALL AMMO, TEST I LAND IMPRESSION WIDTH vs. EXTREME SPREAD	+.73	.063	
2	20 RDS PER MIN, ALL PROCESSES, BALL AMMO, TEST I LONGEST-SHORTEST LAND IMPRESSION vs. EXTREME SPREAD	+.66		.019
3	ALL RATES, ALL PROCESSES, ALL AMMO LAND IMPRESSION WIDTH vs. EXTREME SPREAD	+.73	.054	
4	ALL RATES, ALL PROCESSES, BALL AMMO LAND IMPRESSION WIDTH vs. EXTREME SPREAD	+.75	.052	
5	ALL RATES, ALL PROCESSES, TRACER AMMO LAND IMPRESSION WIDTH vs. EXTREME SPREAD	+.64	.070	
6	ALL RATES, PROCESS A, BALL AMMO LAND IMPRESSION WIDTH vs. EXTREME SPREAD	+.81	.051	
7	ALL RATES, PROCESS B, BALL AMMO LAND IMPRESSION WIDTH vs. EXTREME SPREAD	+.62	.054	
8	ALL RATES, PROCESS C, BALL AMMO LAND IMPRESSION WIDTH vs. EXTREME SPREAD	+.72	.054	
9	100 RDS PER MIN, ALL PROCESSES, BALL AMMO LAND IMPRESSION WIDTH vs. EXTREME SPREAD	+.81	.053	
10	60 RDS PER MIN, ALL PROCESSES, BALL AMMO LAND IMPRESSION WIDTH vs. EXTREME SPREAD	+.71	.052	
11	20 RDS PER MIN, ALL PROCESSES, BALL AMMO LAND IMPRESSION WIDTH vs. EXTREME SPREAD	+.71	.052	
12	ALL RATES, ALL PROCESSES, ALL AMMO LONGEST-SHORTEST LAND IMPRESSION vs. EXTREME SPREAD	+.46		.025

GRAPH NUMBER	GRAPH TITLE	CORRELATION COEFF.	LAND IMP. WIDTH CUTOFF*	LONG-SHORT IMP. CUTOFF*
13	ALL RATES, ALL PROCESSES, BALL AMMO LONGEST-SHORTEST LAND IMPRESSION vs. EXTREME SPREAD	+.44		.019
14	ALL RATES, ALL PROCESSES, TRACER AMMO LONGEST-SHORTEST LAND IMPRESSION vs. EXTREME SPREAD	+.15		**
15	ALL RATES, PROCESS A, BALL AMMO LONGEST-SHORTEST LAND IMPRESSION vs. EXTREME SPREAD	+.55		.016
16	ALL RATES, PROCESS B, BALL AMMO LONGEST-SHORTEST LAND IMPRESSION vs. EXTREME SPREAD	+.01		**
17	ALL RATES, PROCESS C, BALL AMMO LONGEST-SHORTEST LAND IMPRESSION vs. EXTREME SPREAD	+.12		**
18	100 RDS PER MIN, ALL PROCESSES, BALL AMMO LONGEST-SHORTEST LAND IMPRESSION vs. EXTREME SPREAD	+.31		.025
19	60 RDS PER MIN, ALL PROCESSES, BALL AMMO LONGEST-SHORTEST LAND IMPRESSION vs. EXTREME SPREAD	+.12		**
20	20 RDS PER MIN, ALL PROCESSES, BALL AMMO LONGEST-SHORTEST LAND IMPRESSION vs. EXTREME SPREAD	+.65		.017

* CORRESPONDING TO 7" EXTREME SPREAD BASED ON SECOND ORDER REGRESSION LINES

** NO DEFINITE RELATIONSHIP

The correlation coefficient of +.73 for Graph 3 demonstrates the good correlation between land impression width and extreme spread for all three firing rates, all three processes and two types of ammunition. Under identical conditions the correlation coefficient between longest-shortest land impression and extreme spread (as shown on Graph 12) is +.46.

Graphs 6, 7, and 8 demonstrate that good correlation (coefficients of +.82, +.62, +.72) exists between land impression width and extreme spread regardless of barrel manufacturer. On the other hand, the correlation of the longest-shortest land and extreme spread is definitely dependent upon barrel manufacturing processes. Graph 15, with a correlation coefficient of +.55, shows a reasonable dependence for Process A weapons. Graphs 16 and 17 (Process B and C barrels) do not exhibit any substantial correlation, having coefficients of only +.01 and +.12.

Variations in rate of fire do not significantly affect the correlation between land impression width and extreme spread. This is obvious from Graphs 9, 10, and 11 (100 rd/min, 60 rd/min and 20 rd/min) which have coefficients of +.81, +.71 and +.71 respectively. However, rate of fire does appear to influence the interdependence of longest-shortest land impression length and extreme spread. This effect is reflected by Graphs 18, 19, and 20 which have correlation coefficients of +.31, +.12, and +.65 for 100, 60 and 20 rounds per minute respectively.

Both ball and tracer ammunition gave good correlations between land impression width and extreme spread with coefficients of +.75 and +.64 respectively (Graphs 4 and 5). The firing of ball ammunition gave a correlation of +.44 between longest-shortest land impression and extreme spread on Graph 13. The correlation for tracer ammunition was much worse, as shown by the coefficient of +.15 for Graph 14.

The second-order regression lines plotted on Graphs 3 and 12 were used to determine the land impression width and longest-shortest land impression which corresponded to 7 inches extreme spread which is the rifle's field rejection point. The appropriate land impression width was found to be .054 inches and the longest-shortest impression was found to be .025 inches.

The excellent reproducibility of the test can be verified by comparing the correlation coefficients of Graphs 1 and 11 (+.73 and +.71) and of Graphs 2 and 20 (+.66 and +.65) which have identical parameters.

CONCLUSIONS

Six significant conclusions that can be drawn from this program are:

(1) Projectile engraving characteristics do undergo mutations during the accuracy life of M16A1 Rifles.

(2) Three distinct mutations have been identified. One of the mutations is a widening of the grooves engraved in projectiles by some barrels as those barrels reach the end of their accuracy lives. Another mutation is an increase in the difference in lengths of the longest and shortest grooves engraved in one projectile. The third mutation is the occurrence of gouges, nicks, scrapes, and general surface roughness on some projectiles fired from some barrels which had passed their useful accuracy life.

(3) All three mutations exhibit some correlation with accuracy.

(4) Increase in land impression width is the mutation which has the best correlation with accuracy.

(5) There is a strong correlation between land impression width and accuracy regardless of rate of fire, type of ammunition fired, or barrel manufacturing process.

(6) If land impression width were to be used as a gage of weapon accuracy, .054 inch land impression width would correspond to the field rejection criteria of 7 inches extreme spread for a ten-shot target at a range of 100 yards.

RECOMMENDATIONS

a. A major obstacle to the testing of weapon accuracy at training bases by observing projectile mutations is the development of a method of trapping projectiles on a production line basis. Thus, a study should be undertaken to develop a practical method of trapping projectiles.

b. The scope of this program was limited to the isolation of projectile mutations and the demonstration of positive correlations between the mutations and accuracy. In order to understand why the correlations exist, theoretical bases for the correlations should be conceived, developed, and finally supported by means of math modeling of the interior and exterior ballistics of the projectile.

APPENDIX A

TABLE II - TEST I DATA

PROCESS	RIFLE	NO. OF RDS FIRED	LAND IMP. WIDTH	LONGEST-SHORTEST LAND	JACKET MUTILATION	EXTREME SPREAD
A	1	5000	.051	.030	NO	2.3
A	2	5000	.065	.015	NO	2.5
A	3	5000	.059	.010	NO	3.4
B	4	5000	.055	.010	NO	2.8
B	5	5000	.055	.015	NO	3.5
B	6	5000	.056	.010	NO	4.8
C	7	5000	.048	.015	NO	3.6
C	8	5000	.050	.015	NO	4.5
C	9	5000	.061	.015	NO	4.2
A	1	10000	.055	.010	NO	2.6
A	2	10000	.059	.010	NO	2.7
A	3	10000	.054	.015	NO	2.9
B	4	10000	.050	.010	NO	2.6
B	5	10000	.050	.015	NO	3.0
B	6	10000	.052	.010	NO	2.8
C	7	10000	.053	.010	NO	3.4
C	8	10000	.056	.015	NO	4.5
C	9	10000	.053	.015	NO	3.4
A	1	15000	.076	.015	NO	13.5
A	2	15000	.074	.025	NO	15.1
A	3	15000	.072	.020	NO	17.6
B	4	15000	.060	.045	NO	10.9
B	5	15000	.055	.010	NO	4.0
B	6	15000	.063	.010	NO	5.1
C	7	15000	.060	.010	NO	4.3
C	8	15000	.060	.010	NO	4.7
C	9	15000	.061	.015	NO	7.8
A	1	20000	.071	.070	NO	15.5
A	2	20000	.077	.025	NO	14.0
A	3	20000	.078	.055	NO	16.1
B	4	20000	.054	.030	YES	16.1
B	5	20000	.055	.015	NO	3.4
B	6	20000	.052	.035	YES	10.4
C	7	20000	.055	.010	NO	7.9
C	8	20000	.058	.020	NO	5.3
C	9	20000	.056	.030	NO	6.3

TABLE III - TEST II DATA

CONTRACTOR	RIFLE NO.	RATE OF FIRE	AMMUNITION	NO. OF RDS FIRED	LAND IMP WIDTH	LARGEST SHORTEST LAND	JACKET MUTILATION	EXTREME SPREAD
A	3	100	M196	0	.038	.007	NO	2.7
A	3	100	M196	2,000	.043	.015	NO	3.4
A	3	100	M196	4,000	.048	.015	NO	4.3
A	3	100	M196	6,000	.048	.007	NO	3.7
A	3	100	M196	8,000	.049	.015	NO	3.5
A	3	100	M196	10,000	.048	.015	NO	3.6
A	3	100	M196	12,000	.050	.020	NO	5.6
	6	100	M196	0	.040	.015	NO	3.6
B	6	100	M196	2,000	.043	.008	NO	3.2
B	6	100	M196	4,000	.044	.015	NO	3.4
B	6	100	M196	6,000	.047	.015	NO	3.7
B	6	100	M196	8,000	.048	.010	NO	5.2
B	6	100	M196	10,000	.043	.010	NO	3.3
B	6	100	M196	12,000	.045	.010	NO	3.5
C	9	100	M196	0	.039	.010	NO	4.4
C	9	100	M196	2,000	.045	.015	NO	4.3

CONTRACTOR	RIFLE NO.	RATE OF FIRE	AMMUNITION	NO. OF RDS FIRED	LAND IMP WIDTH	LARGEST SHORTEST LAND	JACKET MUTILATION	EXTREME SPREAD
C	9	100	M196	4,000	.045	.015	NO	3.6
C	9	100	M196	6,000	.049	.010	NO	5.0
C	9	100	M196	8,000	.048	.010	NO	3.6
C	9	100	M196	10,000	.045	.010	NO	4.3
C	9	100	M196	12,000	.053	.010	NO	4.6
A	12	60	M196	0	.041	.015	NO	3.2
A	12	60	M196	5,000	.046	.012	NO	4.1
A	12	60	M196	10,000	.050	.018	NO	3.1
A	12	60	M196	15,000	.053	.015	NO	4.9
B	15	60	M196	0	.041	.020	NO	3.8
B	15	60	M196	5,000	.043	.010	NO	3.9
L	15	60	M196	10,000	.045	.010	NO	2.4
B	15	60	M196	15,000	.045	.015	NO	2.9
C	18	60	M196	0	.039	.020	NO	3.7
C	18	60	M196	5,000	.049	.012	NO	4.1
C	18	60	M196	10,000	.053	.012	NO	5.4

CONTRACTOR	RIFLE NO.	RATE OF FIRE	AMMUNITION	NO. OF RDS FIRED	LAND IMP WIDTH	LARGEST SHORTEST LAND	JACKET MUTILATION	EXTREME SPREAD
C	18	60	M196	15,000	.047	.010	NO	4.5
A	21	20	M196	0	.039	.020	NO	3.5
A	21	20	M196	5,000	.045	.025	NO	4.7
A	21	20	M196	10,000	.052	.015	NO	5.8
A	21	20	M196	15,000	.048	.020	NO	5.8
A	21	20	M196	20,000	.060	.016	NO	5.0
A	21	20	M196	25,000	.063	.020	NO	6.3
A	21	20	M196	30,000	.058	.015	NO	6.8
B	24	20	M196	0	.038	.025	NO	4.0
B	24	20	M196	5,000	.042	.010	NO	3.6
B	24	20	M196	10,000	.043	.015	NO	2.9
B	24	20	M196	15,000	.041	.010	NO	2.9
B	24	20	M196	20,000	.055	.008	NO	4.0
B	24	20	M196	25,000	.050	.012	NO	6.2
B	24	20	M196	30,000	.053	.010	NO	3.8
C	27	20	M196	0	.038	.010	NO	3.7

CONTRACTOR	RIFLE NO.	RATE OF FIRE	AMMUNITION	NO. OF RDS FIRED	LAND IMP WIDTH	LARGEST SHORTEST LAND	JACKET MUTILATION	EXTREME SPREAD
C	27	20	M196	5,000	.043	.008	NO	3.7
C	27	20	M196	10,000	.042	.015	NO	3.5
C	27	20	M196	15,000	.043	.013	NO	3.7
C	27	20	M196	20,000	.050	.010	NO	4.2
C	27	20	M196	25,000	.050	.010	NO	7.1
C	27	20	M196	30,000	.051	.010	NO	5.7

CONTRACTOR	RIFLE NO.	RATE OF FIRE	AMMUNITION	NO. OF RDS FIRED	LAND IMP WIDTH	LARGEST SHORTEST LAND	JACKET MUTILATION	EXTREME SPREAD
A	1	100	M193	0	.039	.015	NO	4.2
A	1	100	M193	2,000	.049	.010	NO	4.1
A	1	100	M193	4,000	.049	.012	NO	4.4
A	1	100	M193	6,000	.054	.015	NO	6.9
A	1	100	M193	8,000	.060	.010	NO	11.1
A	1	100	M193	10,000	.066	.020	NO	11.6
A	1	100	M193	12,000	.065	.055	NO	14.4
A	2	100	M193	0	.040	.015	NO	4.2
A	2	100	M193	2,000	.047	.015	NO	3.6
A	2	100	M193	4,000	.049	.015	NO	5.3
A	2	100	M193	6,000	.055	.012	NO	6.2
A	2	100	M193	8,000	.060	.015	NO	8.3
A	2	100	M193	10,000	.062	.025	NO	8.0
A	2	100	M193	12,000	.068	.025	NO	14.4
B	4	100	M193	0	.038	.020	NO	2.5
B	4	100	M193	2,000	.043	.005	NO	3.4

CONTRACTOR	RIFLE NO.	RATE OF FIRE	AMMUNITION	NO. OF RDS FIRED	LAND IMP WIDTH	LARGEST SHORTEST LAND	JACKET MUTILATION	EXTREME SPREAD
B	4	100	M193	4,000	.043	.012	NO	3.7
B	4	100	M193	6,000	.051	.010	NO	7.5
B	4	100	M193	8,000	.048	.010	NO	7.2
B	4	100	M193	10,000	.050	.010	NO	10.7
B	4	100	M193	12,000	.055	.007	NO	8.3
B	5	100	M193	0	.041	.010	NO	4.4
B	5	100	M193	2,000	.044	.007	NO	4.2
B	5	100	M193	4,000	.049	.015	NO	3.7
B	5	100	M193	6,000	.051	.012	NO	5.8
B	5	100	M193	8,000	.050	.012	NO	4.5
B	5	100	M193	10,000	.049	.012	NO	7.4
B	5	100	M193	12,000	.052	.010	NO	5.3
C	7	100	M193	0	.039	.020	NO	3.8
C	7	100	M193	2,000	.048	.015	NO	3.4
C	7	100	M193	4,000	.049	.015	NO	4.4
C	7	100	M193	6,000	.051	.025	NO	5.8

CONTRACTOR	RIFLE NO.	RATE OF FIRE	AMMUNITION	NO. OF RDS FIRED	LAND IMP WIDTH	LARGEST SHORTEST LAND	JACKET MUTILATION	EXTREME SPREAD
C	7	100	M193	8,000	.053	.015	NO	6.6
C	7	100	M193	10,000	.053	.020	NO	8.4
C	7	100	M193	12,000	.056	.010	NO	13.6
C	8	100	M193	0	.038	.015	NO	4.7
C	8	100	M193	2,000	.044	.020	NO	3.8
C	8	100	M193	4,000	.050	.015	NO	5.1
C	8	100	M193	6,000	.053	.010	NO	6.0
C	8	100	M193	8,000	.054	.010	NO	7.3
C	8	100	M193	10,000	.057	.010	NO	9.3
C	8	100	M193	12,000	.058	.010	NO	14.4
A	10	60	M193	0	.038	.025	NO	3.5
A	10	60	M193	5,000	.053	.010	NO	6.7
A	10	60	M193	10,000	.055	.030	NO	8.8
A	10	60	M193	15,000	.059	.020	NO	13.2
A	11	60	M193	0	.039	.015	NO	3.3
A	11	60	M193	5,000	.048	.015	NO	5.2

CONTRACTOR	RIFLE NO.	RATE OF FIRE	AMMUNITION	NO. OF RDS FIRED	LAND IMP WIDTH	LARGEST SHORTEST LAND	JACKET MUTILATION	EXTREME SPREAD
A	11	60	M193	10,000	.060	.020	NO	9.6
A	11	60	M193	15,000	.060	.055	NO	8.6
B	13	60	M193	0	.039	.022	NO	4.8
B	13	60	M193	5,000	.045	.010	NO	3.7
B	13	60	M193	10,000	.046	.015	NO	8.9
B	13	60	M193	15,000	.047	.010	NO	11.2
B	14	60	M193	0	.039	.012	NO	3.6
B	14	60	M193	5,000	.049	.015	NO	4.2
B	14	60	M193	10,000	.053	.015	NO	7.2
B	14	60	M193	15,000	.053	.020	NO	8.0
C	16	60	M193	0	.038	.010	NO	4.3
C	16	60	M193	5,000	.054	.015	NO	3.3
C	16	60	M193	10,000	.058	.015	NO	8.0
C	16	60	M193	15,000	.058	.015	NO	11.1
C	17	60	M193	0	.038	.025	NO	3.3
C	17	60	M193	5,000	.055	.013	NO	5.7

CONTRACTOR	RIFLE NO.	RATE OF FIRE	AMMUNITION	NO. OF RDS FIRED	LAND IMP WIDTH	LARGEST SHORTEST LAND	JACKET MUTILATION	EXTREME SPREAD
C	17	60	M193	10,000	.058	.016	NO	9.0
C	17	60	M193	15,000	.061	.021	NO	9.5
A	19	20	M193	0	.038	.020	NO	3.8
A	19	20	M193	5,000	.048	.010	NO	4.6
A	19	20	M193	10,000	.050	.012	NO	8.3
A	19	20	M193	15,000	.052	.050	NO	11.6
A	19	20	M193	20,000	.054	.020	NO	12.9
A	19	20	M193	25,000	.058	.055	NO	12.3
A	19	20	M193	30,000	.059	.060	NO	9.3
A	20	20	M193	0	.038	.010	NO	4.7
A	20	20	M193	5,000	.042	.015	NO	5.4
A	20	20	M193	10,000	.052	.025	NO	7.2
A	20	20	M193	15,000	.054	.015	NO	8.5
A	20	20	M193	20,000	.059	.035	NO	13.8
A	20	20	M193	25,000	.060	.035	NO	13.4
A	20	20	M193	30,000	.055	.030	NO	13.3

CONTRACTOR	RIFLE NO.	RATE OF FIRE	AMMUNITION	NO. OF RDS FIRED	LAND IMP WIDTH	LARGEST SHORTEST LAND	JACKET MUTILATION	EXTREME SPREAD
B	22	20	M193	0	.039	.010	NO	3.2
B	22	20	M193	5,000	.045	.010	NO	4.2
B	22	20	M193	10,000	.053	.010	NO	5.8
B	22	20	M193	15,000	.053	.015	NO	9.2
B	22	20	M193	20,000	.058	.008	NO	8.5
B	22	20	M193	25,000	.060	.015	NO	6.3
B	22	20	M193	30,000	.065	.020	NO	7.9
B	23	20	M193	0	.038	.015	NO	3.7
B	23	20	M193	5,000	.045	.010	NO	4.0
B	23	20	M193	10,000	.044	.010	NO	3.5
B	23	20	M193	15,000	.044	.010	NO	6.2
B	23	20	M193	20,000	.050	.015	NO	5.2
B	23	20	M193	25,000	.055	.015	NO	7.6
B	23	20	M193	30,000	.058	.020	NO	8.9
C	25	20	M193	0	.040	.020	NO	4.5
C	25	20	M193	5,000	.046	.010	NO	4.1

[illegible]	[illegible]	[illegible]	[illegible]	[illegible] RDS FIRED	[illegible]	[illegible]	[illegible]	EXTREME SPREAD
C	25	20	M193	10,000	.046	.010	NO	6.4
C	25	20	M193	15,000	.053	.017	NO	7.4
C	25	20	M193	20,000	.058	.050	NO	6.7
C	25	20	M193	25,000	.053	.020	NO	8.9
C	25	20	M193	30,000	.063	.045	NO	13.5
C	26	20	M193	0	.039	.010	NO	3.6
C	26	20	M193	5,000	.044	.015	NO	4.2
C	26	20	M193	10,000	.051	.015	NO	4.4
C	26	20	M193	15,000	.053	.010	NO	5.9
C	26	20	M193	20,000	.055	.012	NO	4.8
C	26	20	M193	25,000	.055	.015	NO	7.3
C	26	20	M193	30,000	----	----	--	---

APPENDIX B

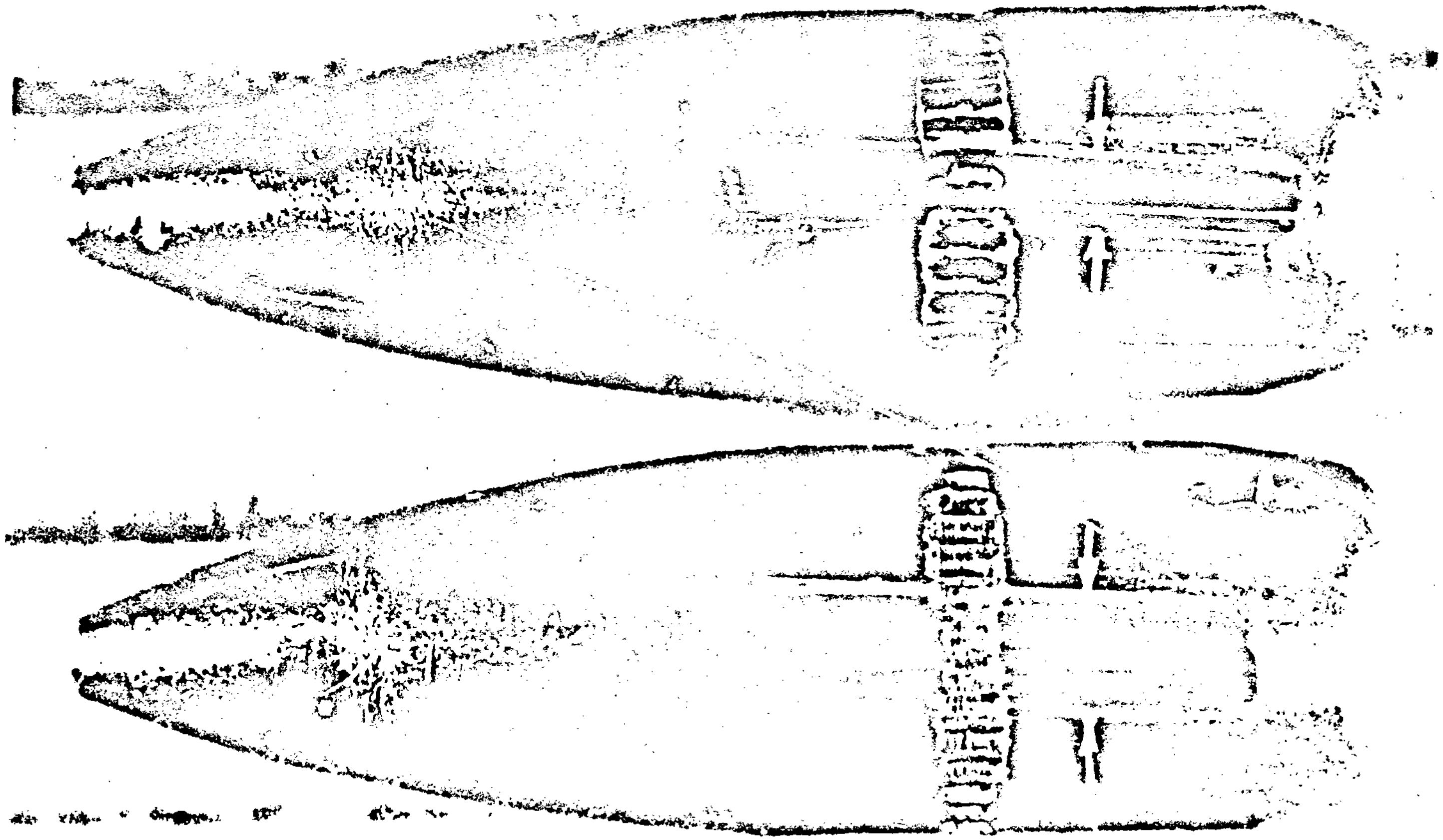


FIGURE 1

PROCESS "A", WEAPON #1, TYPICAL ENGRAVING AT 5000 RDS (TOP) AND 20,000 RDS (BOTTOM). 10.5X 11-199-2155/AMC-72

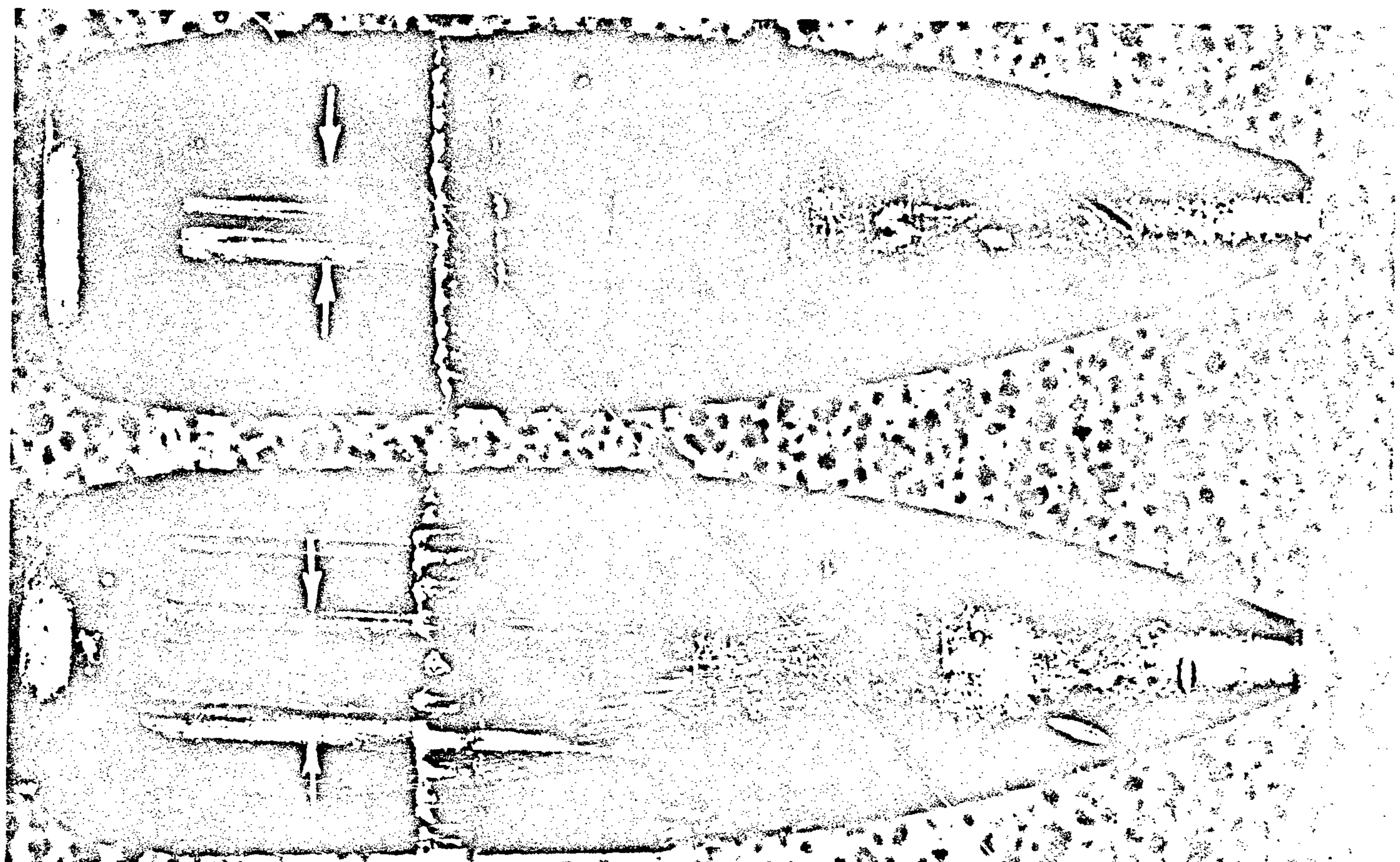


FIGURE 2

PROCESS "A", WEAPON #1, TYPICAL ENGRAVING AT 10,000 RDS (TOP) AND 15,000 RDS (BOTTOM). 10.5X 11-199-2166/AMC-72

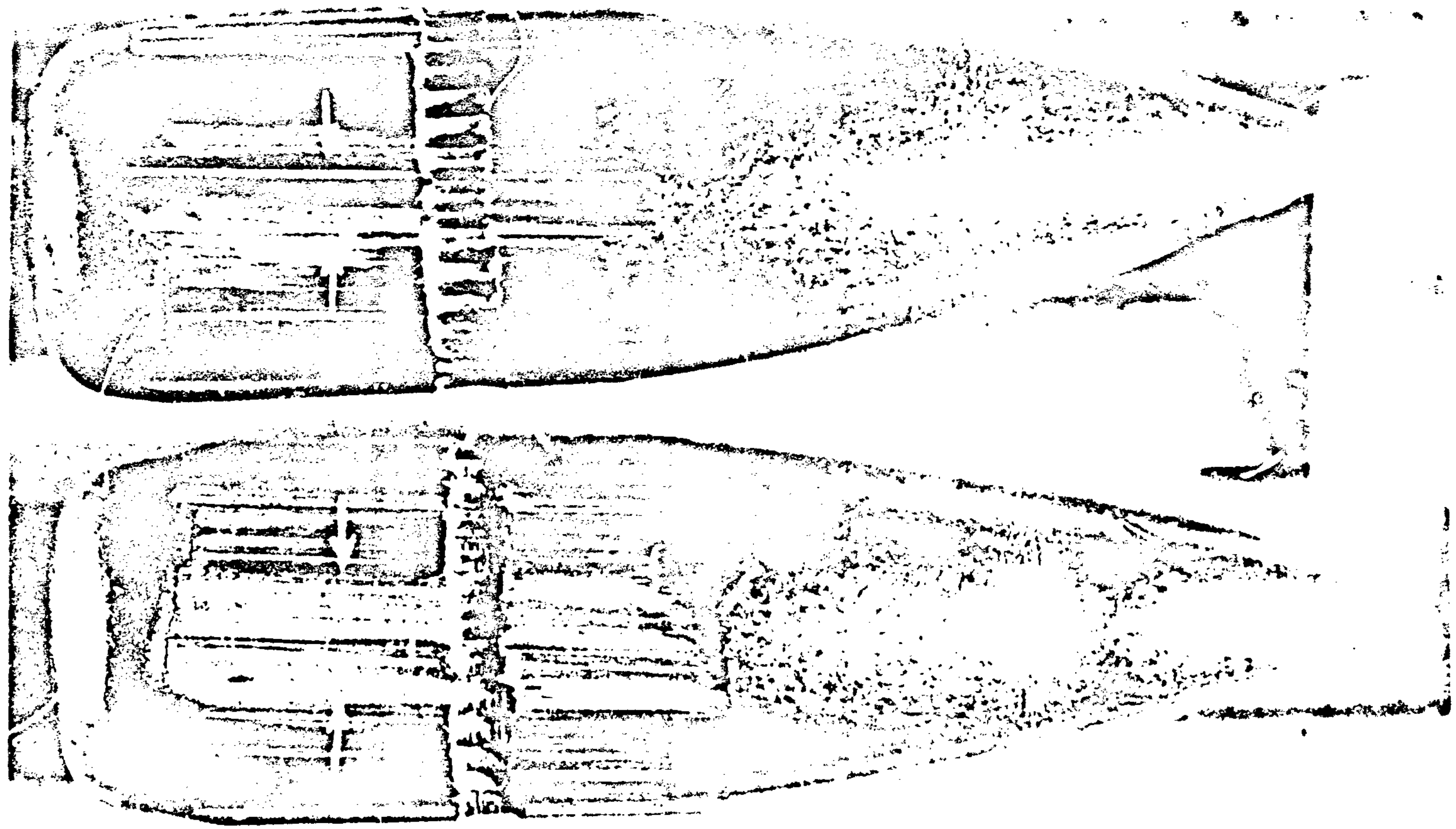


FIGURE 3

PROCESS "A" WEAPON #2, TYPICAL ENGRAVING AT 5000 RDS (TOP) AND 20,000 RDS (BOTTOM). 10.5X 11-199-2151/AMC-72

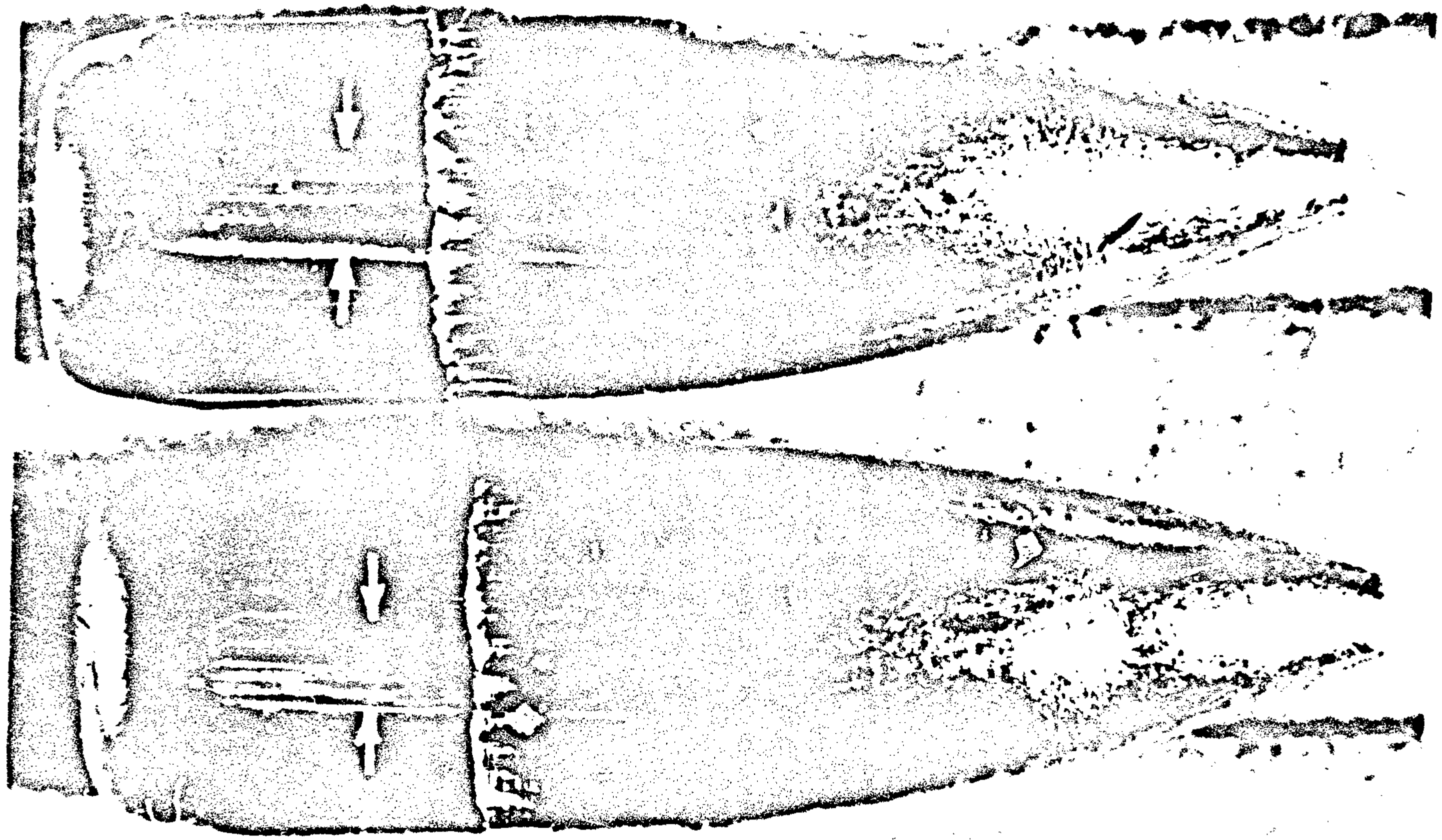


FIGURE 4

PROCESS"B", WEAPON #5, TYPICAL ENGRAVING AT 5000 RDS (TOP) AND 20,000 RDS (BOTTOM). 10.5X 11-199-2152/AMC-72

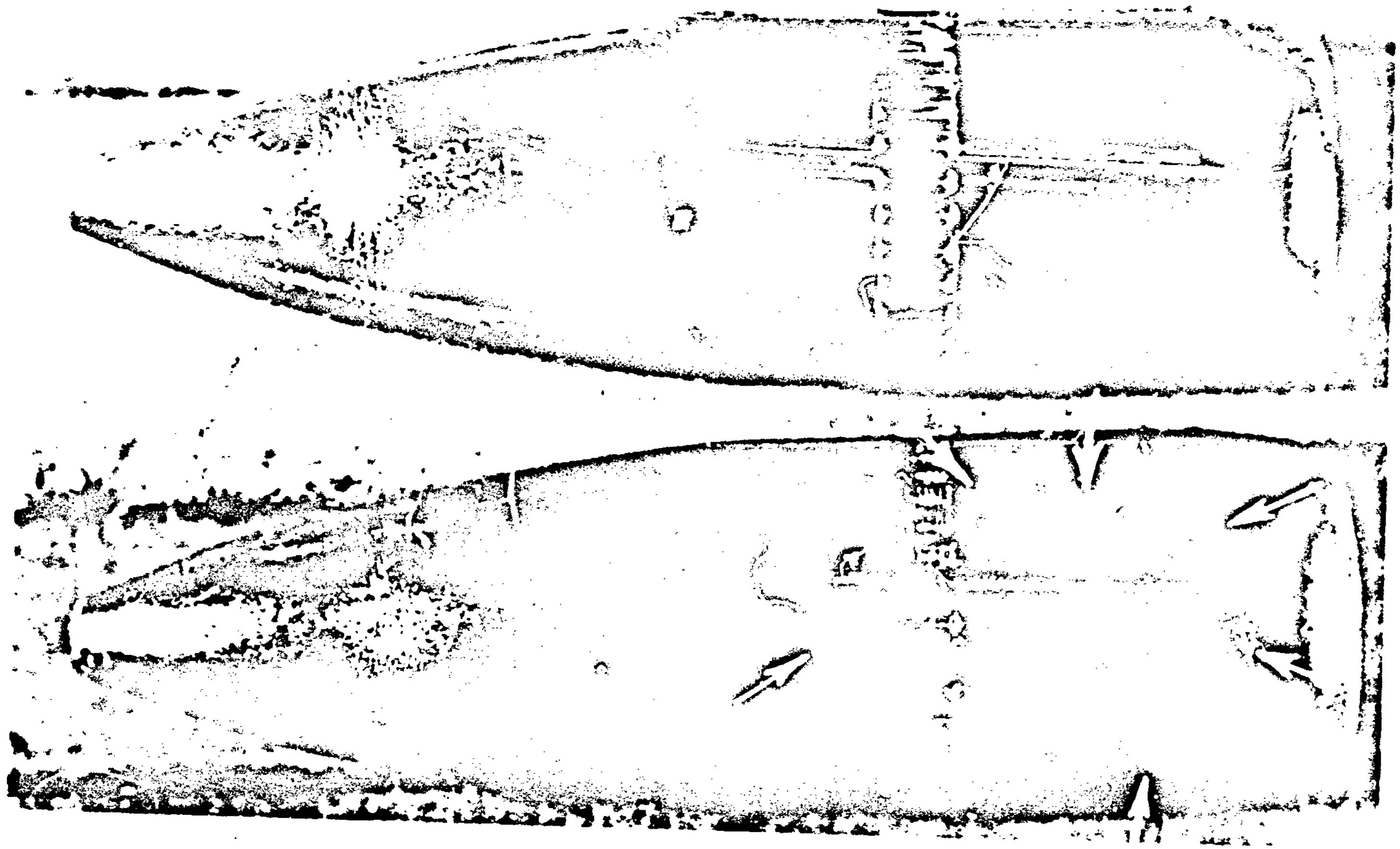


FIGURE 5

PROCESS "B", WEAPON #6, TYPICAL ENGRAVING AT 5000 RDS (TOP) AND 20,000 RDS (BOTTOM). 10.5X 11-199-2156/AMC-72

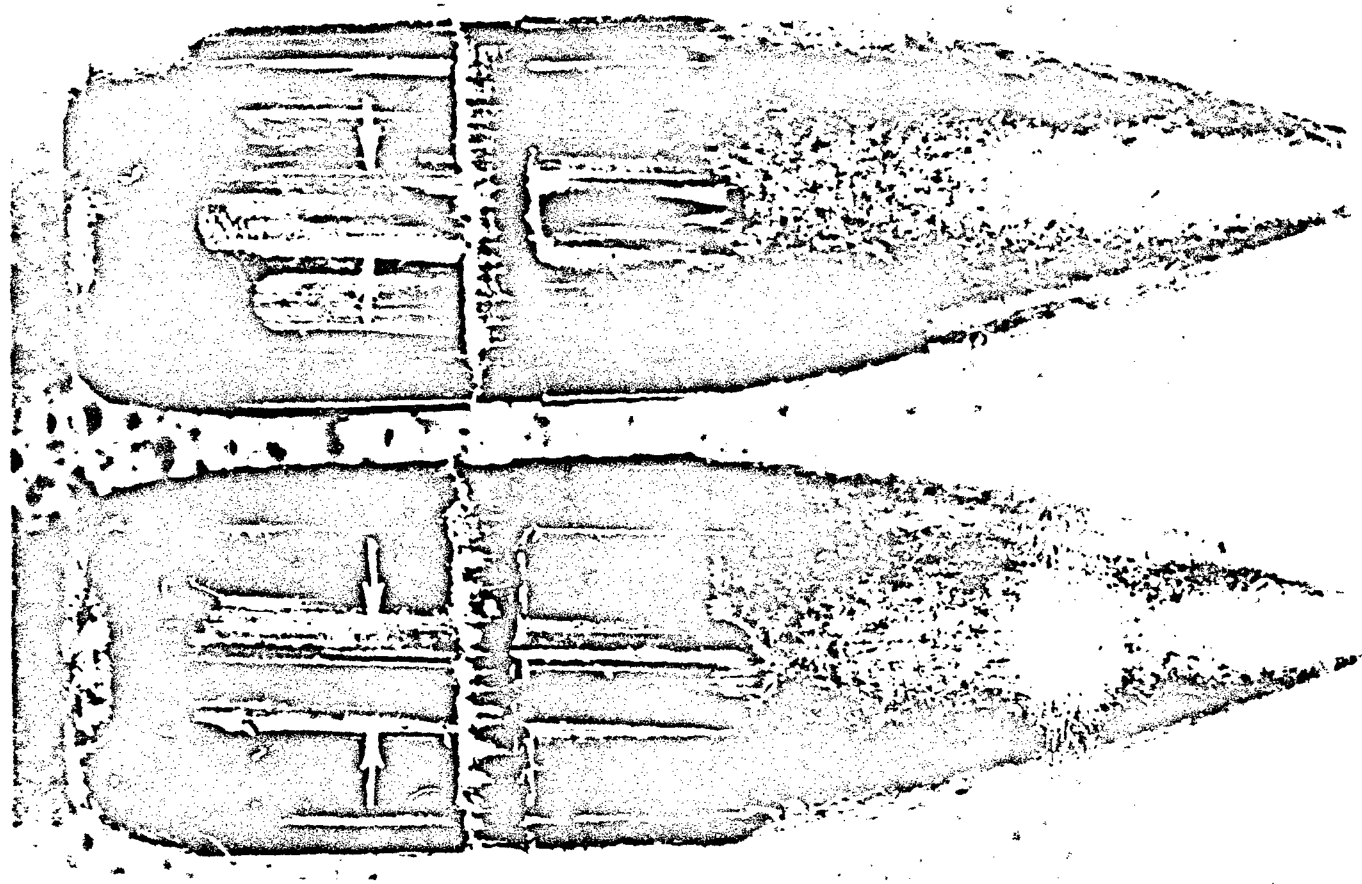


FIGURE 6

PROCESS "B", WEAPON #6, TYPICAL ENGRAVING AT 10,000 RDS (TOP) AND 15,000 RDS (BOTTOM). 10.5X 11-199-2167/AMC-72

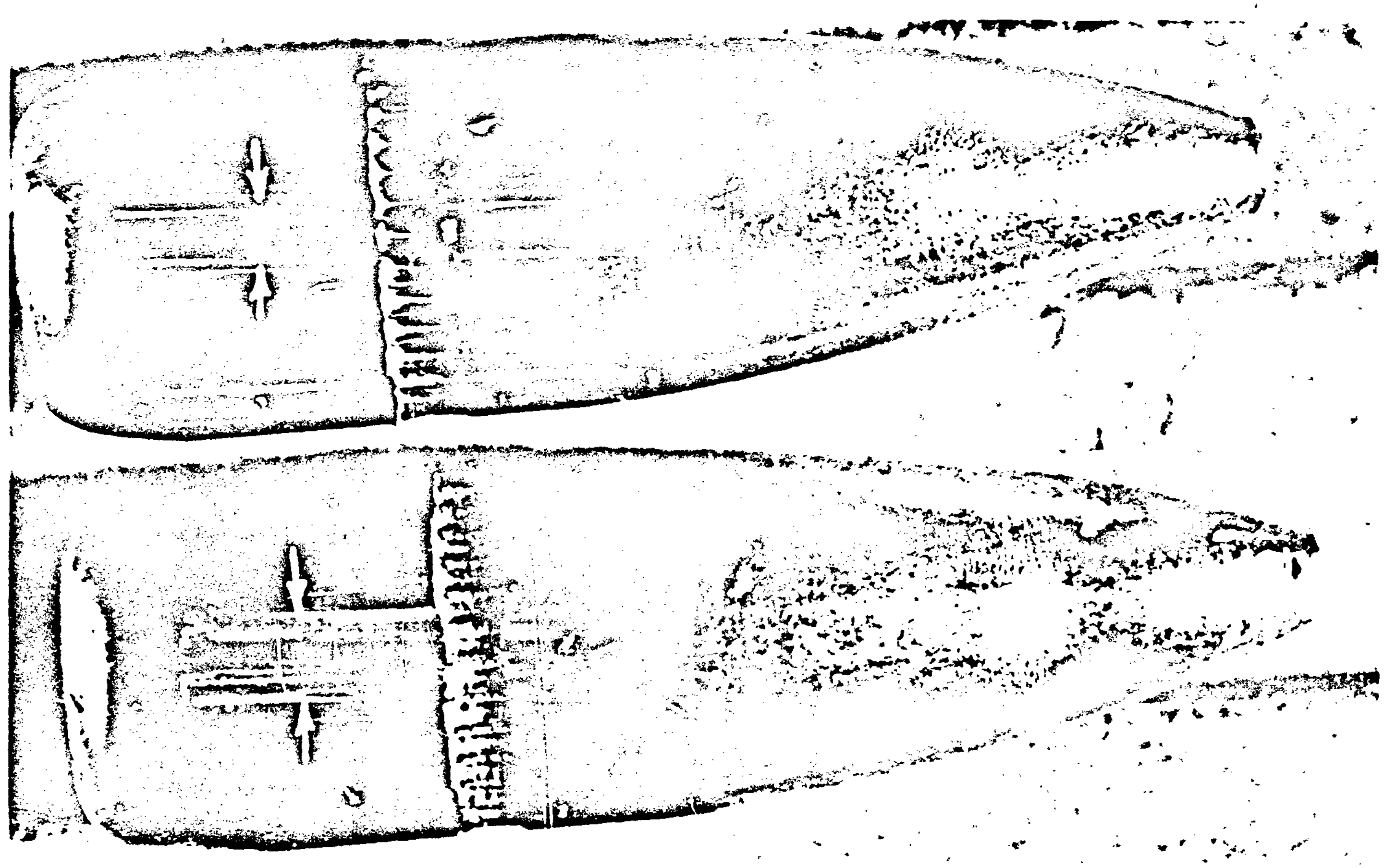


FIGURE 7

PROCESS "C", WEAPON #8, TYPICAL ENGRAVING AT 5000 RDS (TOP) AND 20,000 RDS (BOTTOM). 10.5X 11-199-2153/AMC-72

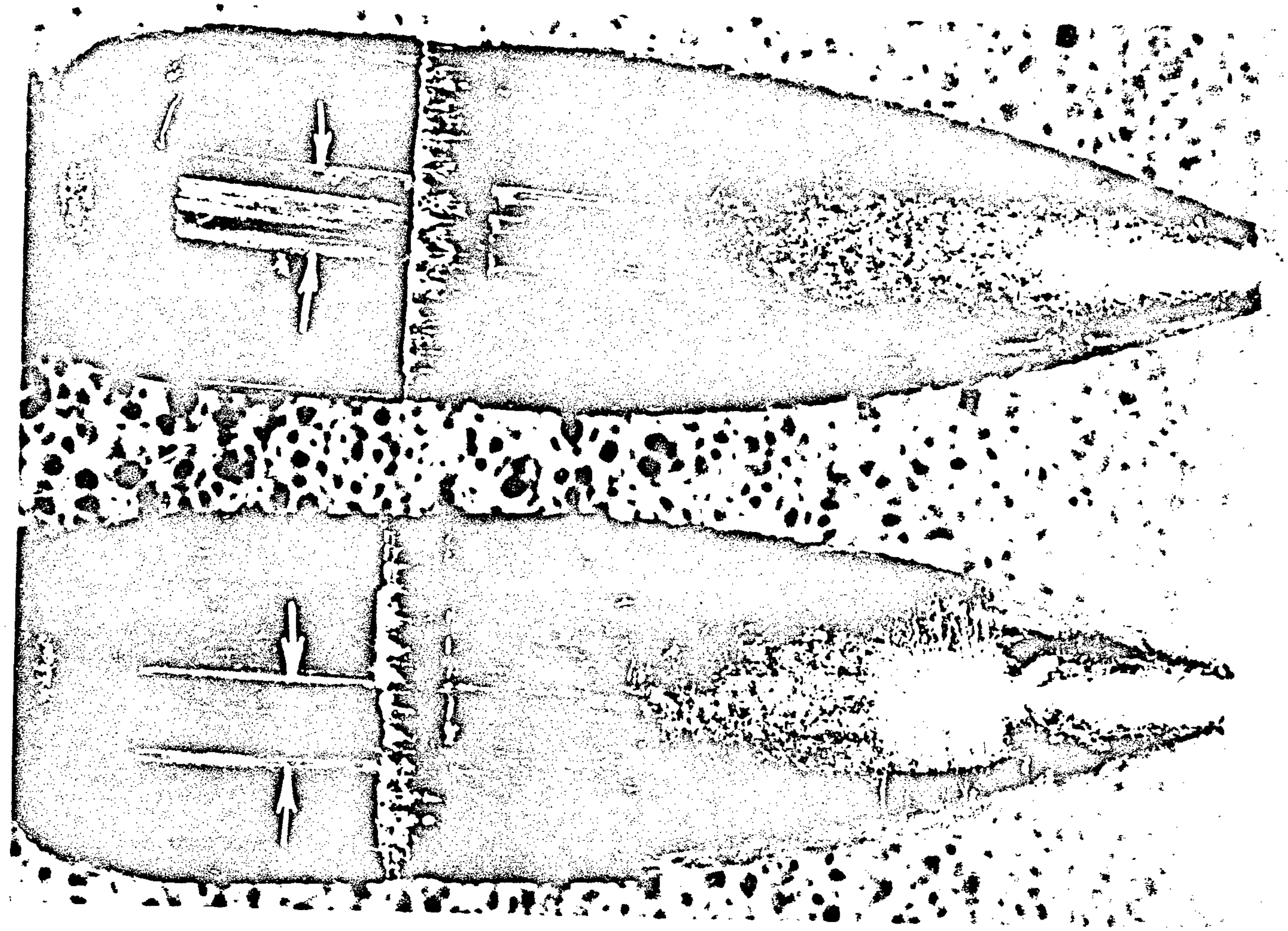


FIGURE 8

PROCESS "C", WEAPON #8, TYPICAL ENGRAVING AT 10,000 RDS (TOP) AND 15,000 RDS (BOTTOM). 10.5X 11-199-2168/AMC-72

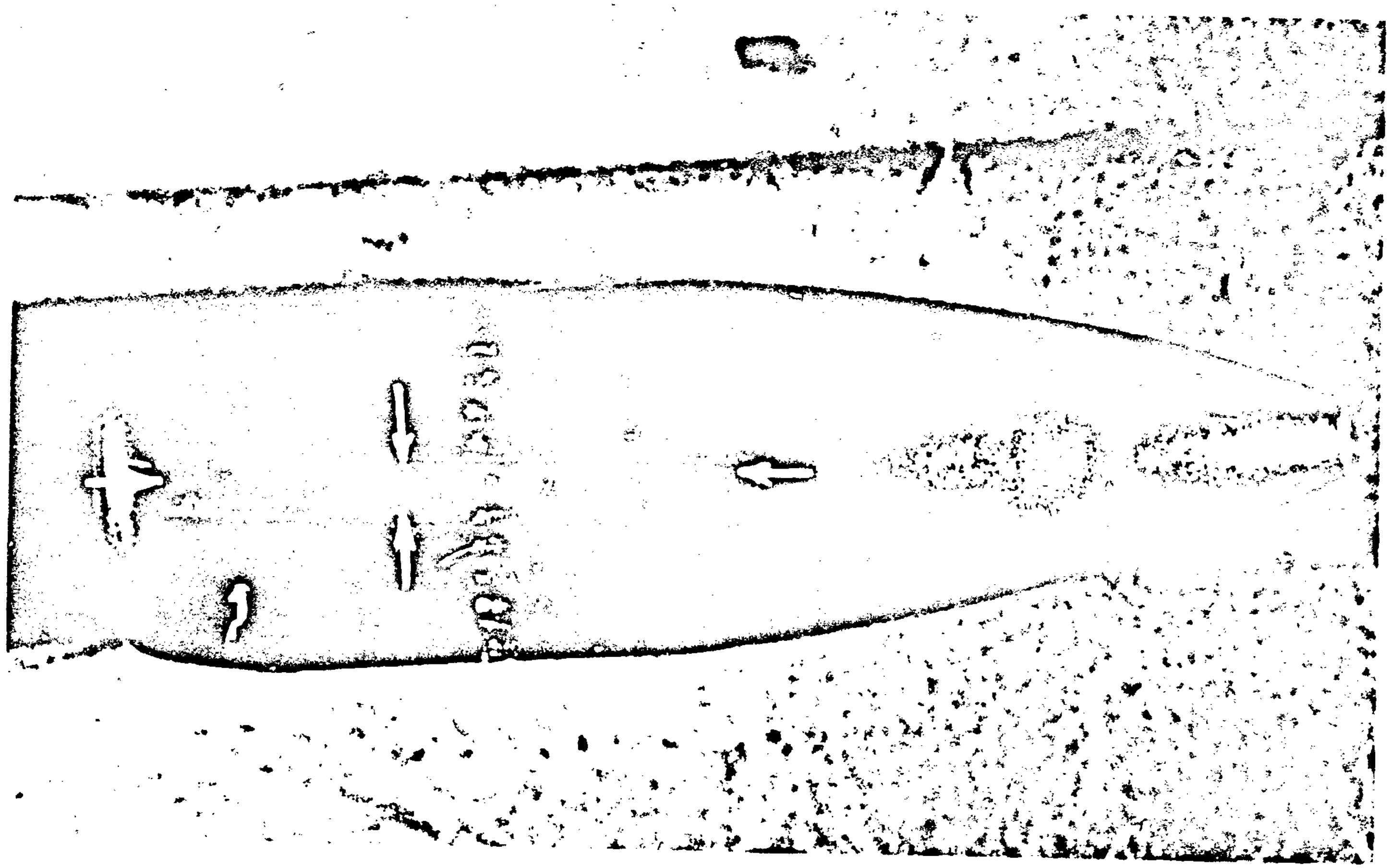


FIGURE 9

PROCESS "A", WEAPON #1, OPPOSITE SIDE OF PROJECTILE SHOWN IN FIGURE 10. NOTE LONG, NARROW LAND IMPRESSION. 10.5X
11-199-2150/AMC-72

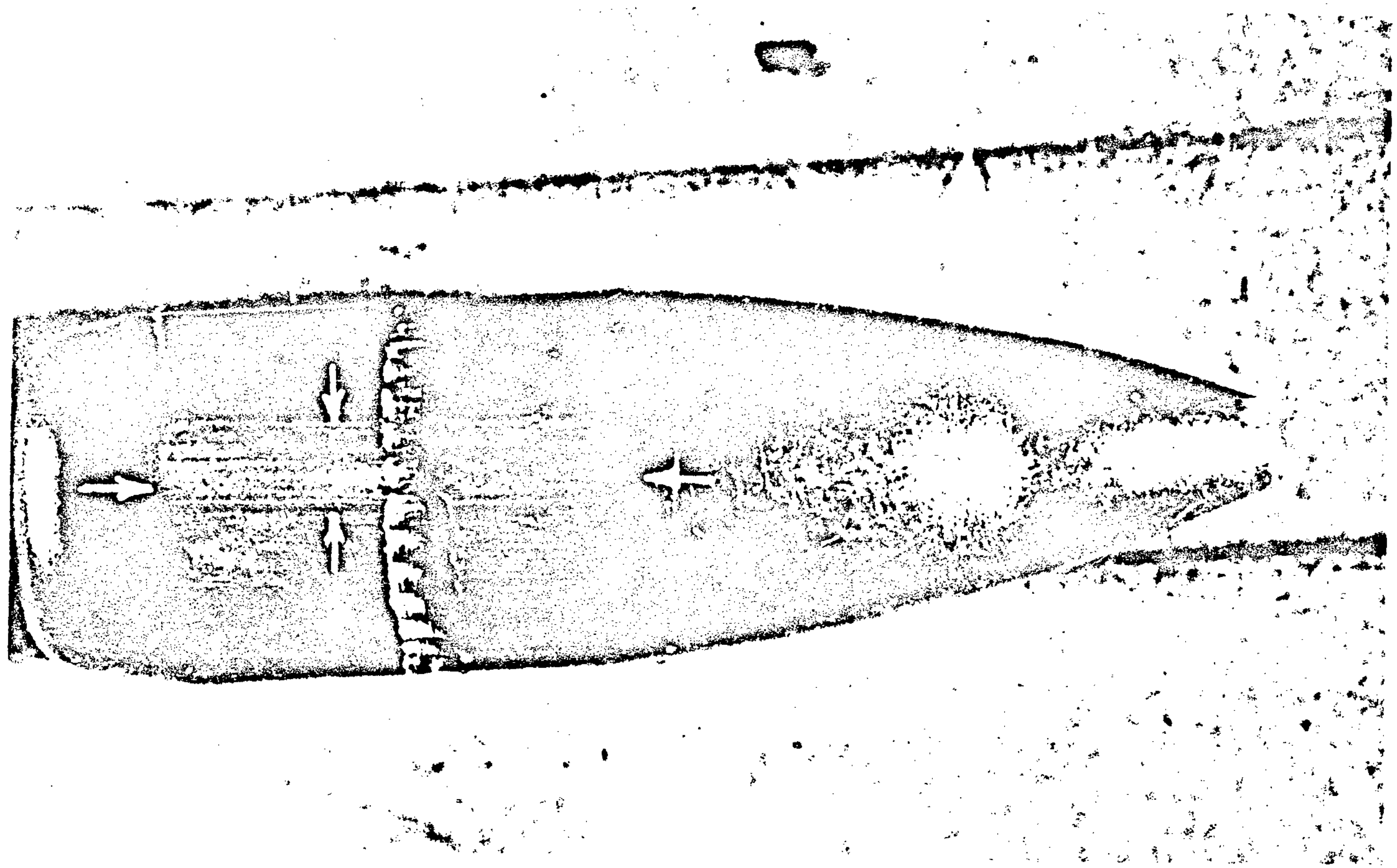


FIGURE 10

PROCESS "A", WEAPON #1, OPPOSITE SIDE OF PROJECTILE SHOWN IN FIGURE 9. NOTE SHORT, WIDE LAND IMPRESSION. 10.5X
11-199-2154/AMC-72

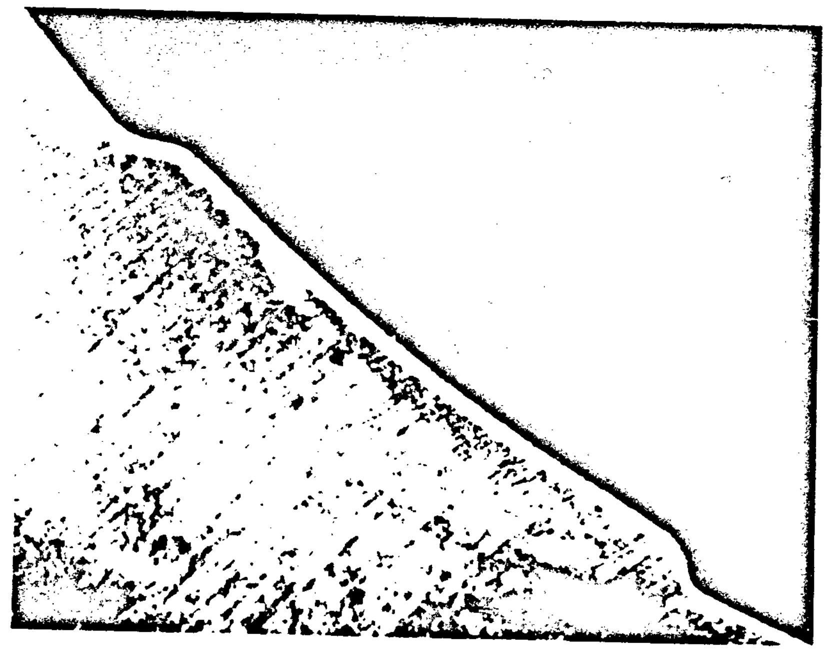


FIGURE II

TYPICAL LAND PROFILE

M16A1 RIFLE BARREL

PROCESS "A" 100X

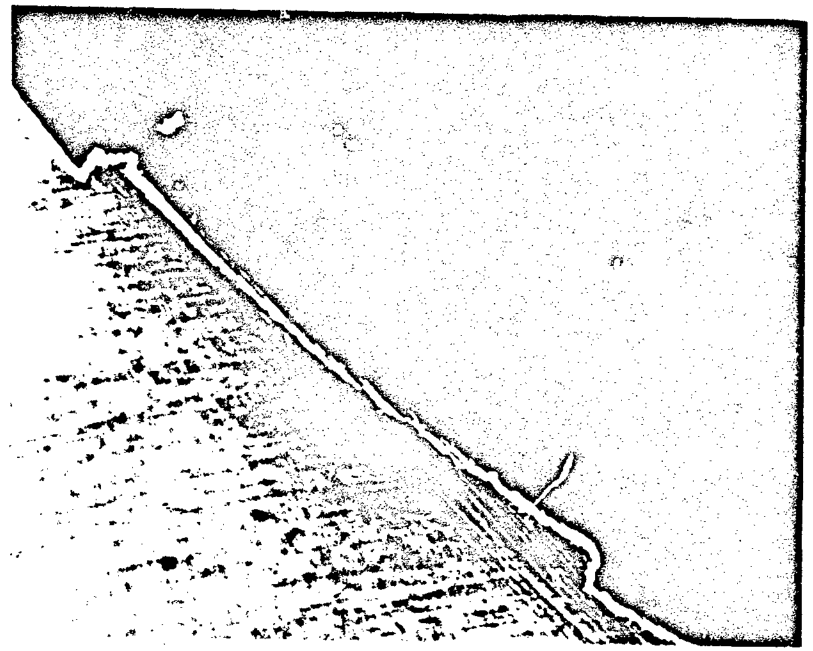


FIGURE 12

TYPICAL LAND PROFILE

M16A1 RIFLE BARREL

PROCESS "B" 100X

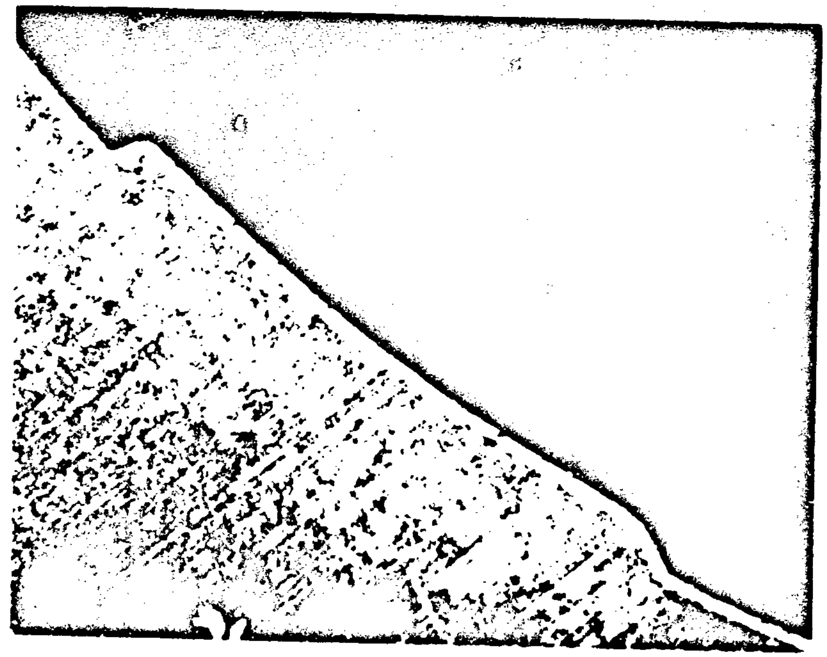


FIGURE 13
TYPICAL LAND PROFILE
M16A1 RIFLE BARREL
PROCESS "C" 100X

APPENDIX C

KEY FOR GRAPHS 1, 2, 9, 10, 11, 18, 19, 20

PROCESS A

PROCESS B

PROCESS C

KEY FOR GRAPHS 6, 7, 8, 15, 16, 17

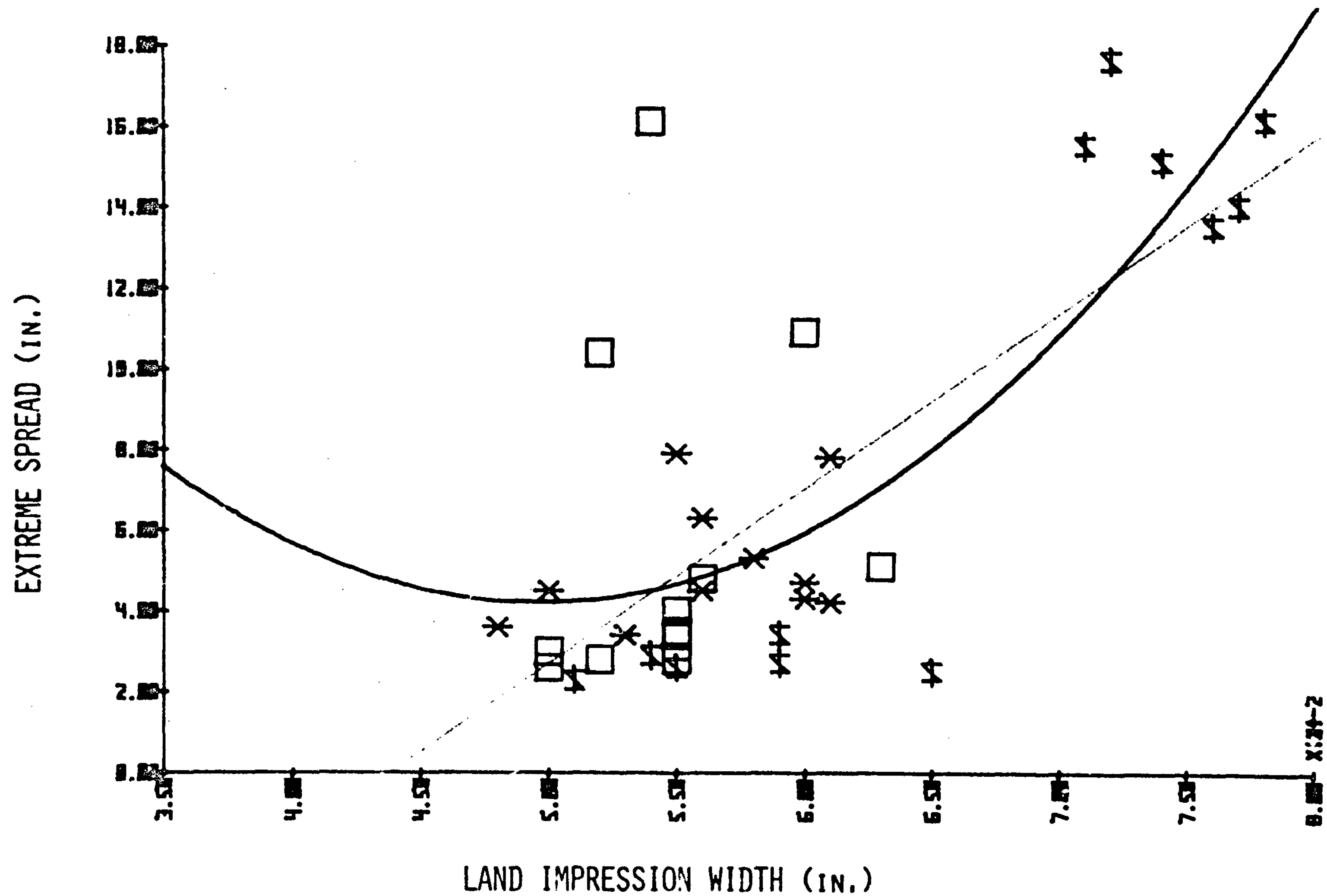
100 RDS PER MIN

60 RDS PER MIN

20 RDS PER MIN

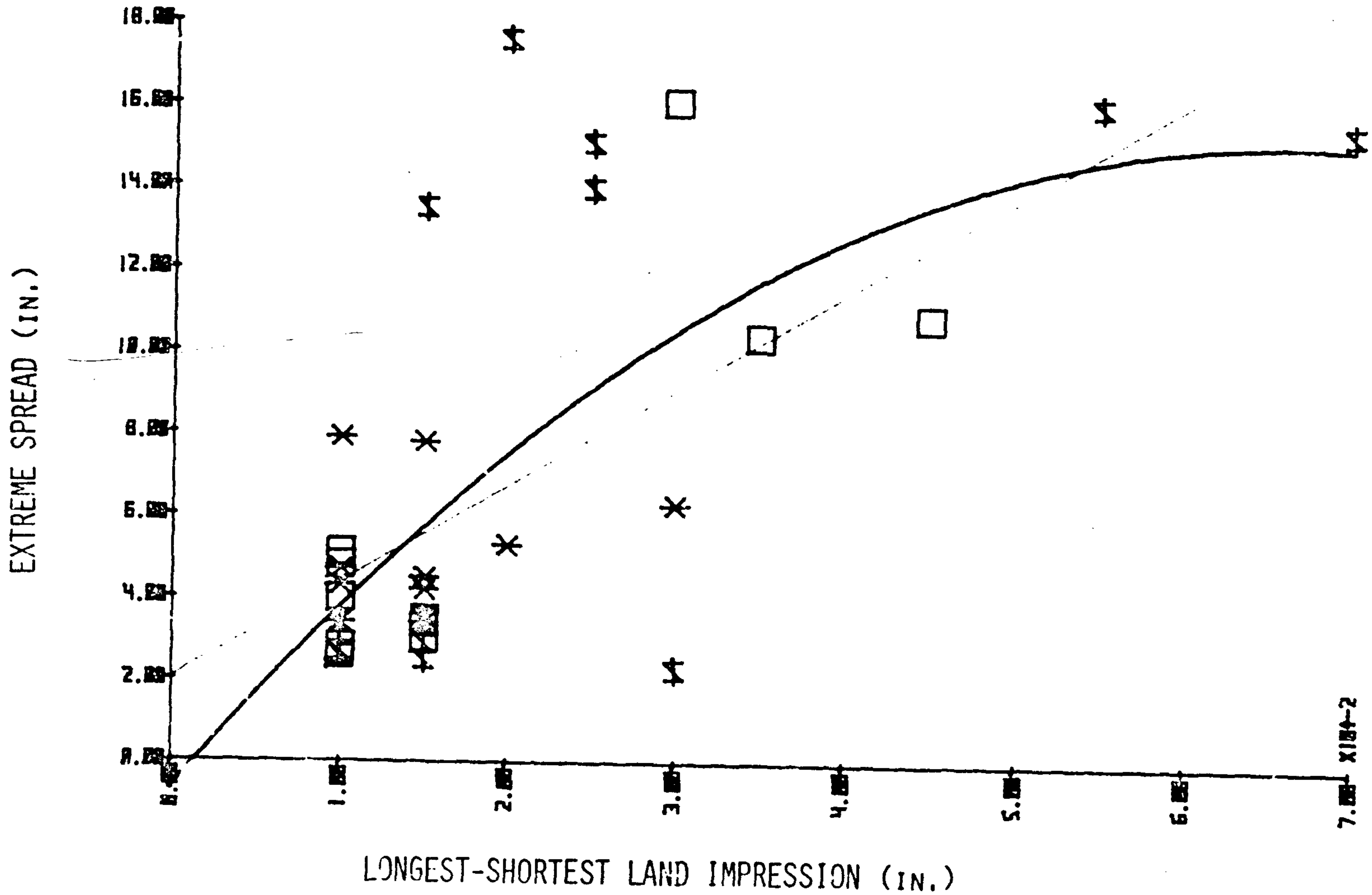
GRAPH 1

20 RDS PER MIN, ALL PROCESSES, BALL AMMO; TEST 1



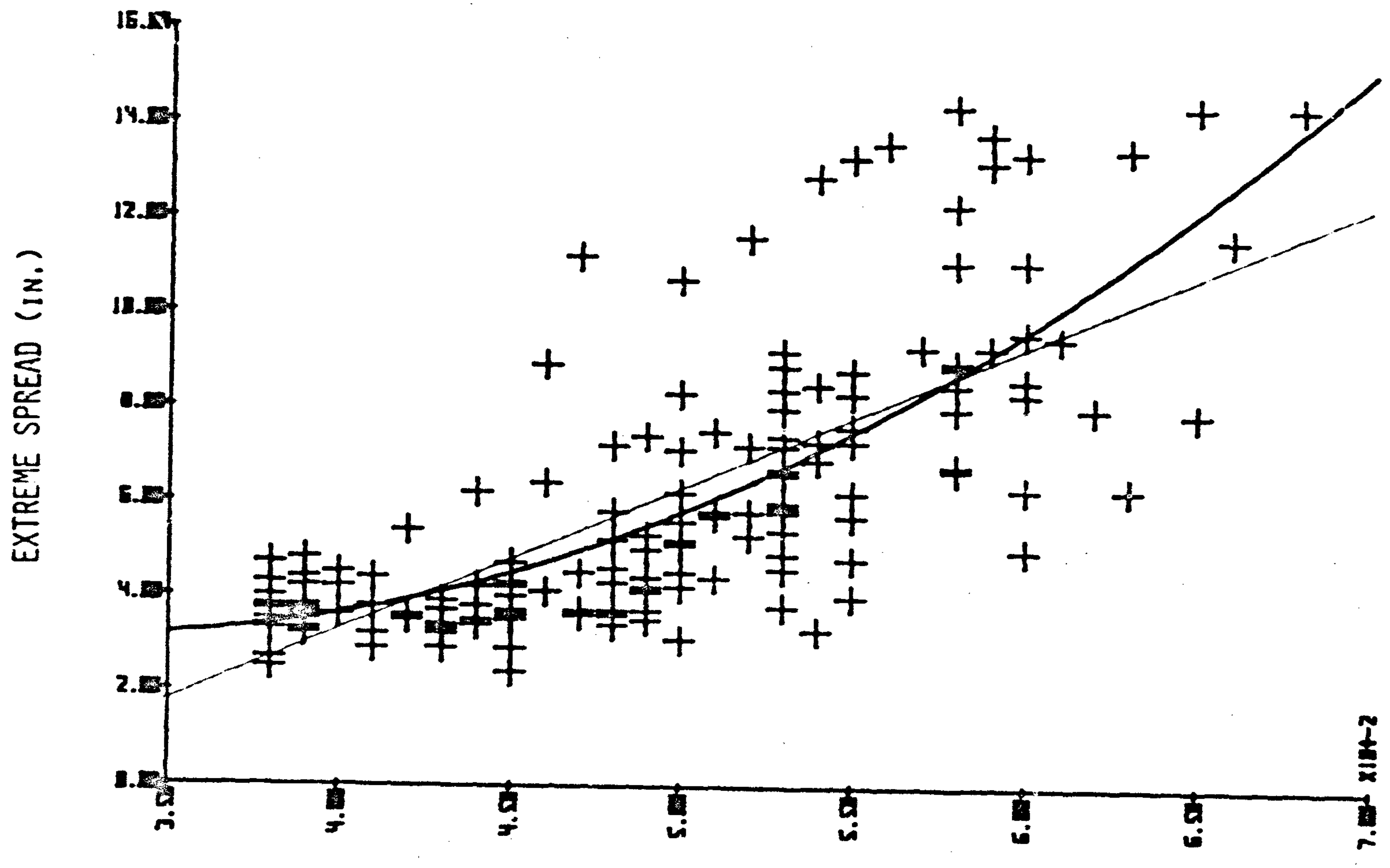
GRAPH 2

20 RDS PER MIN, ALL PROCESSES, BALL AMMO; TEST 1



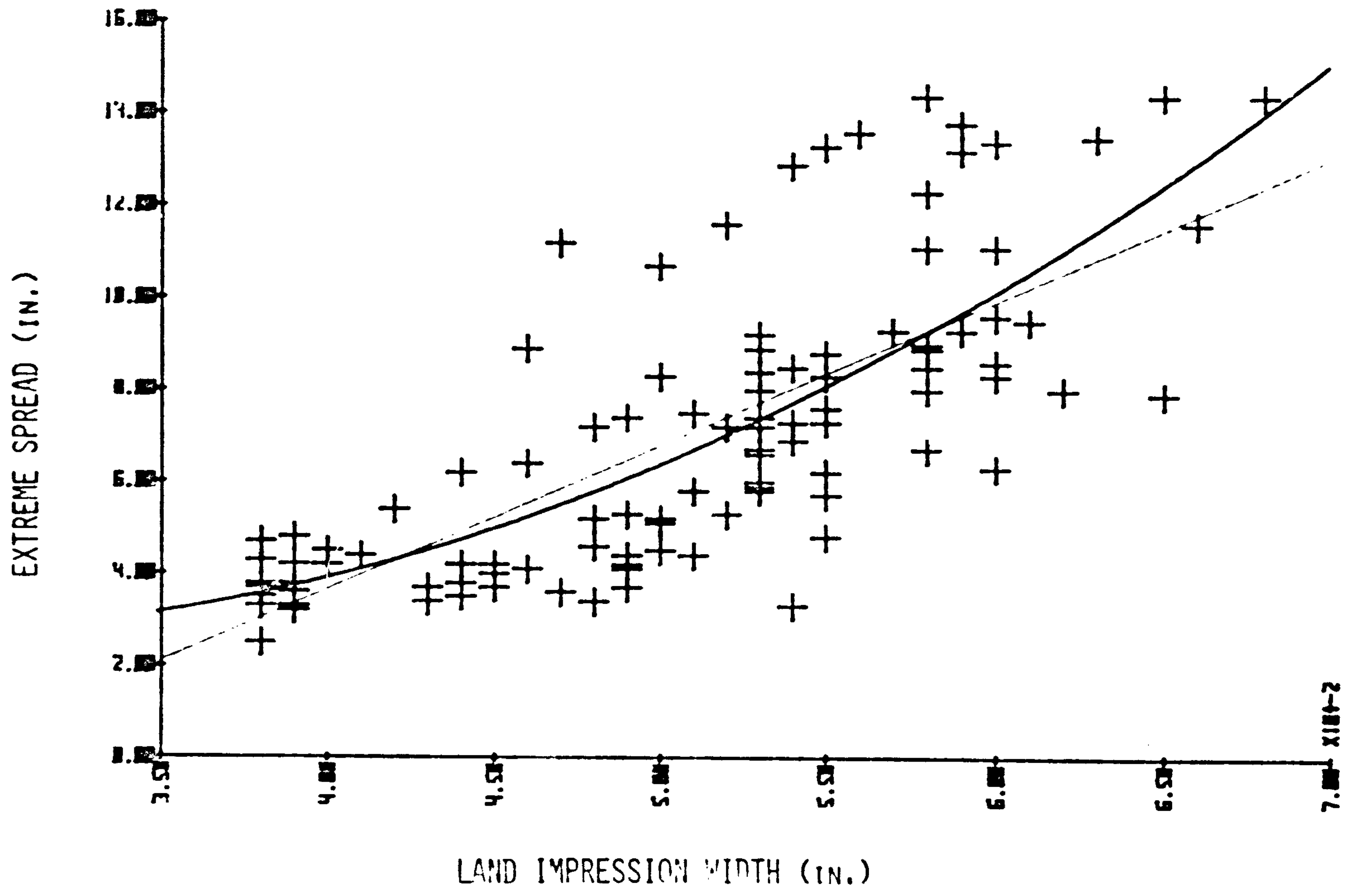
GRAPH 3

ALL RATES, ALL PROCESSES, ALL AMMO



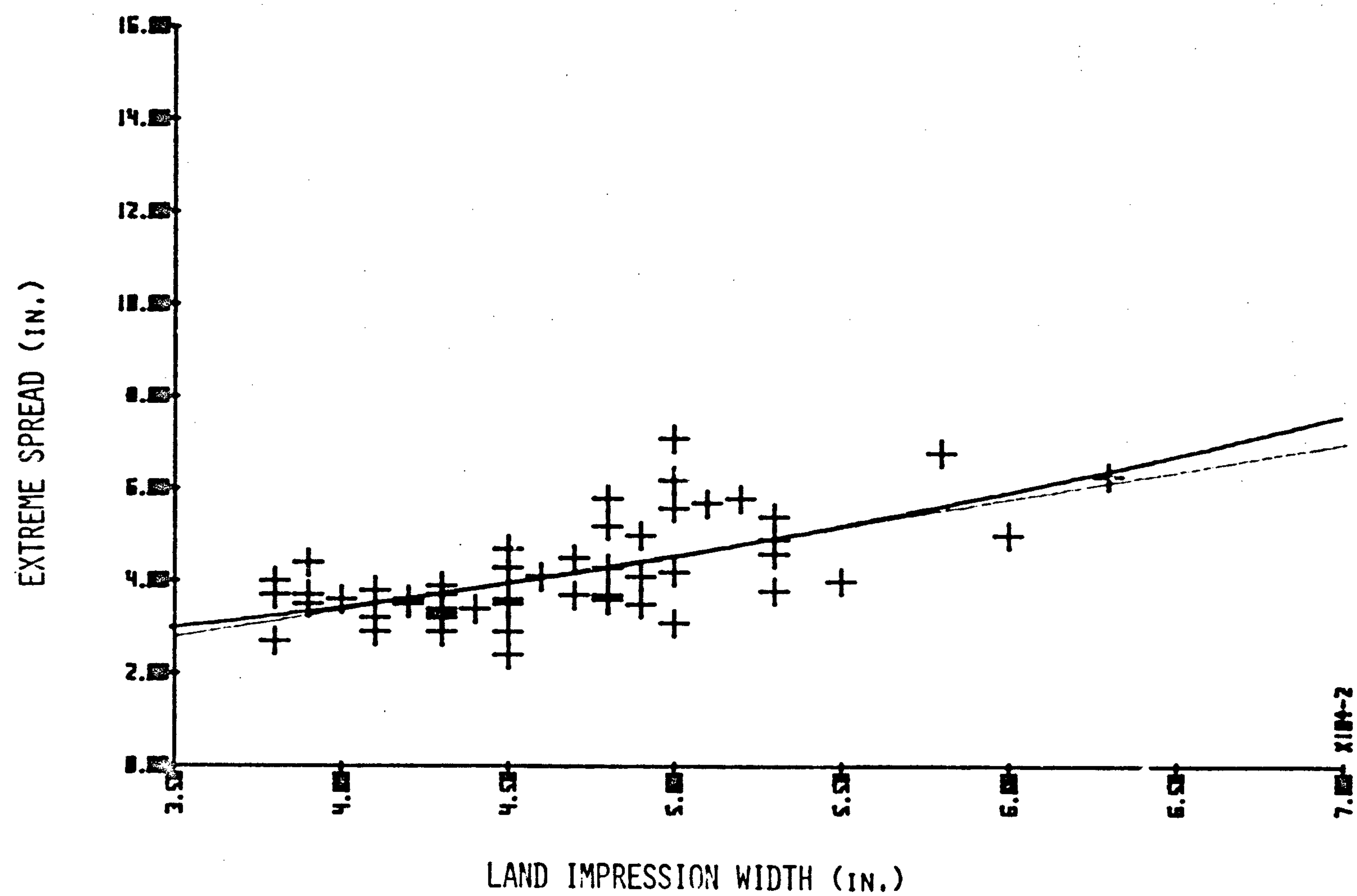
GRAPH 4

ALL RATES, ALL PROCESSES , BALL AMMO



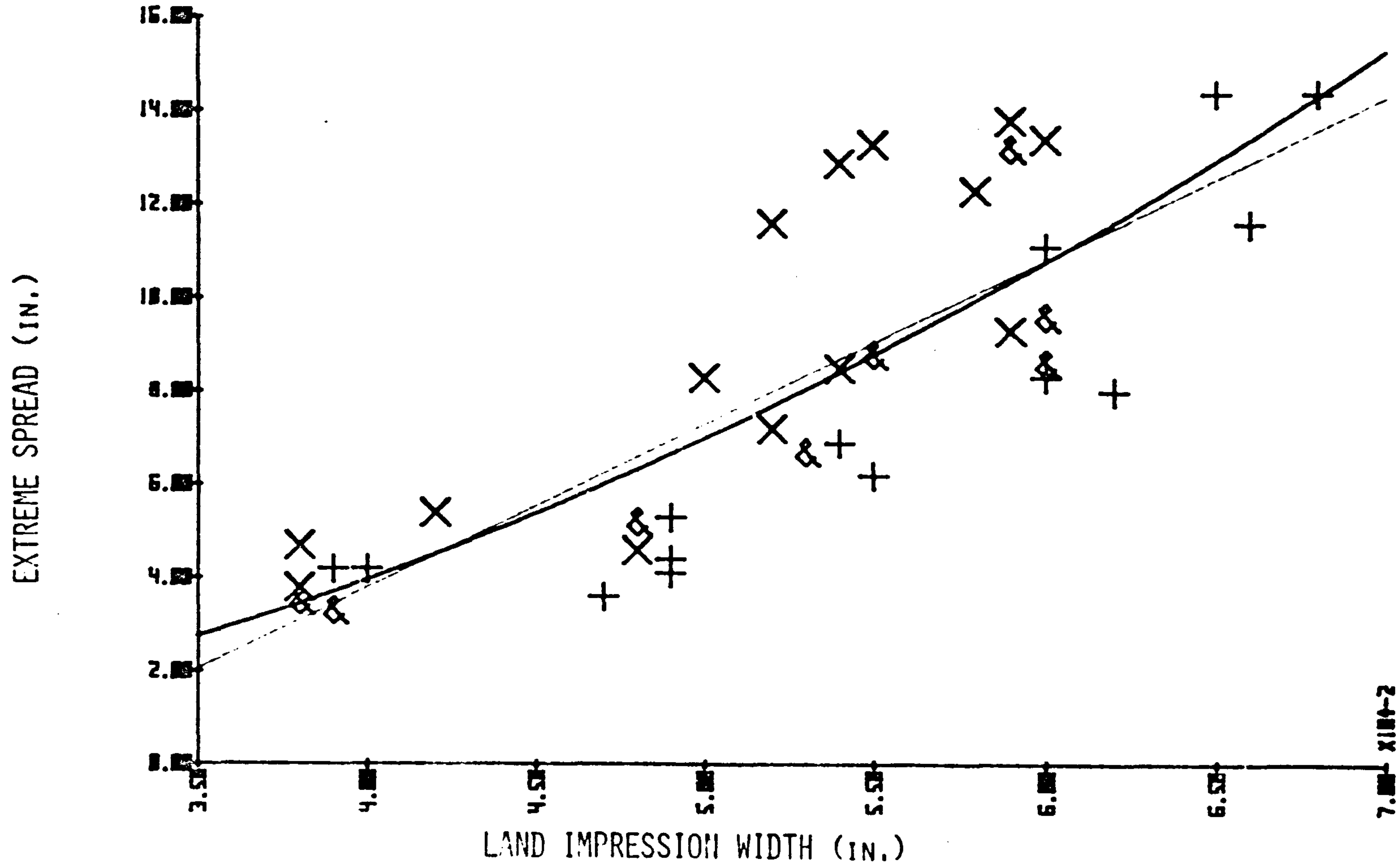
GRAPH 5

ALL RATES, ALL PROCESSES, TRACER AMMO



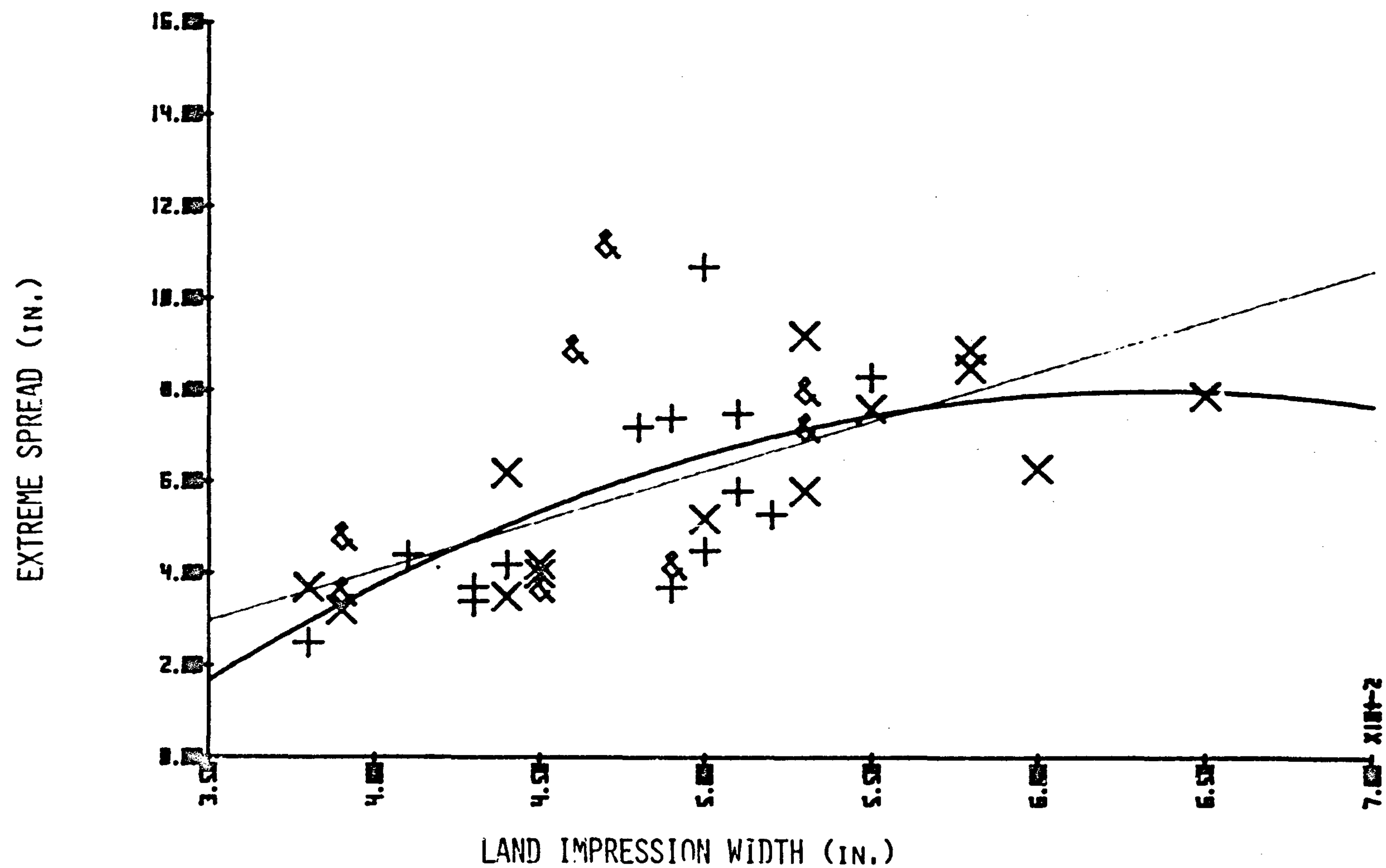
GRAPH 6

ALL RATES, PROCESS A, BALL AMMO



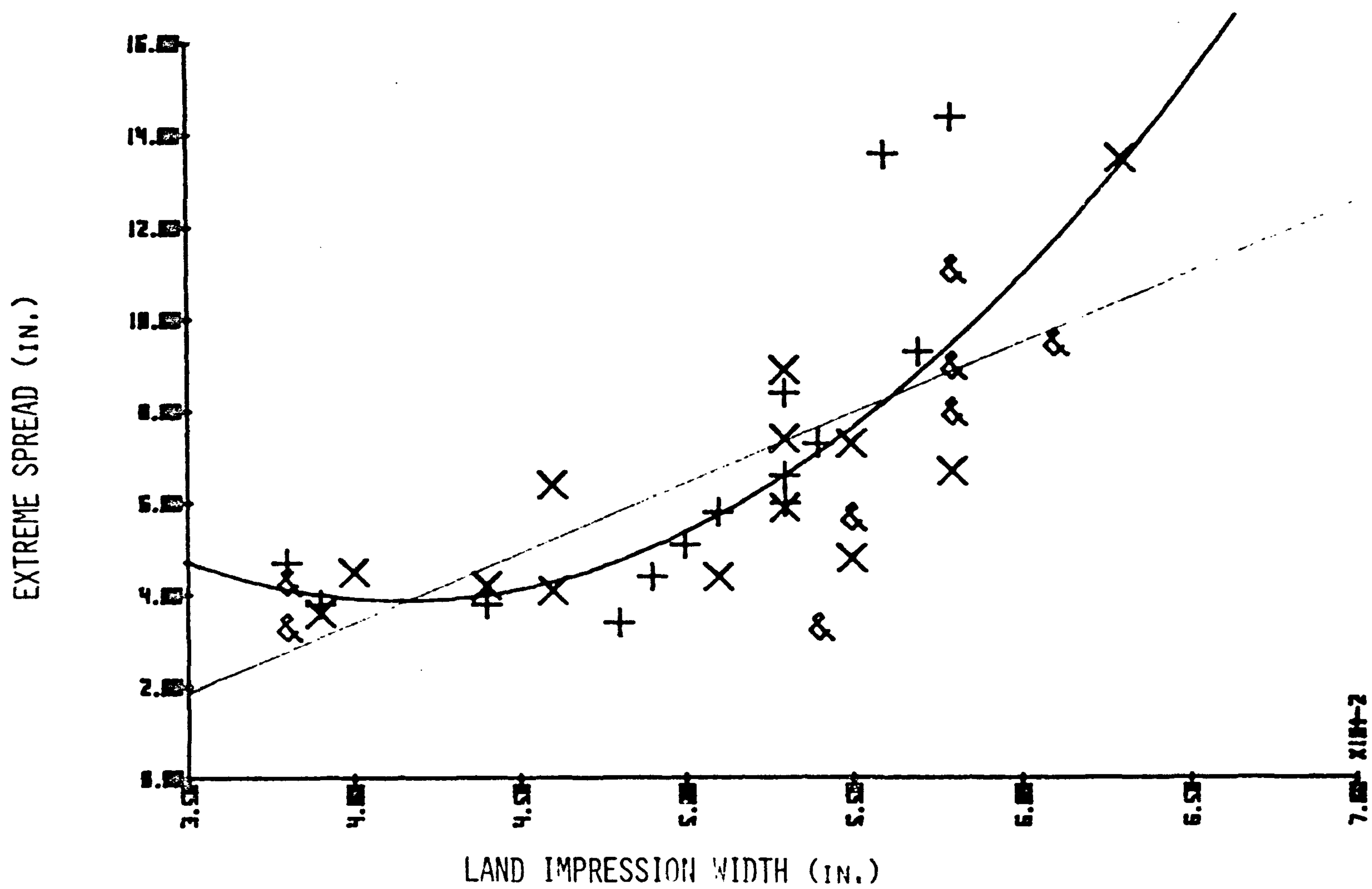
GRAPH 7

ALL RATES, PROCESS B, BALL AMMO



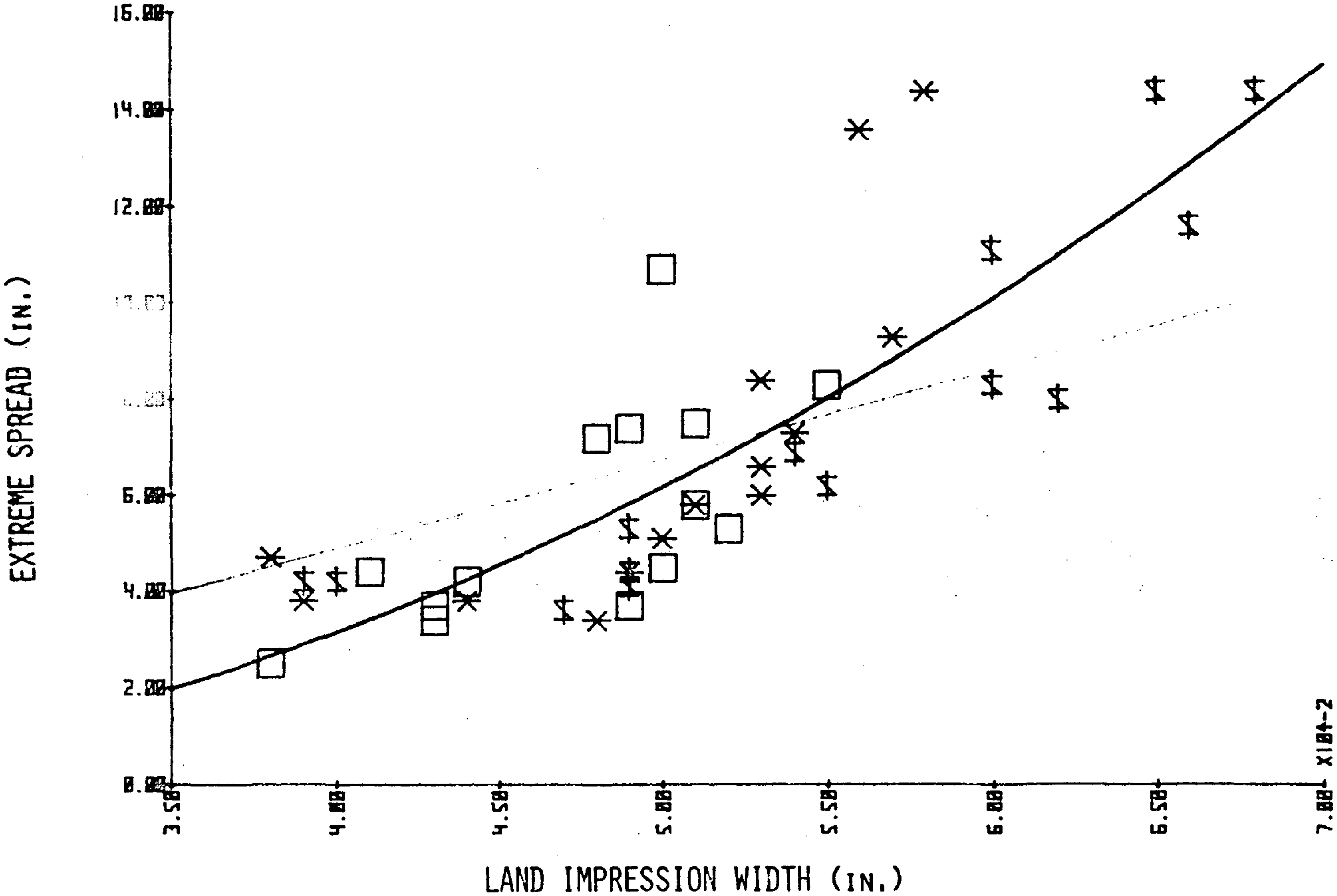
GRAPH 8

ALL RATES, PROCESS C, BALL AMMO



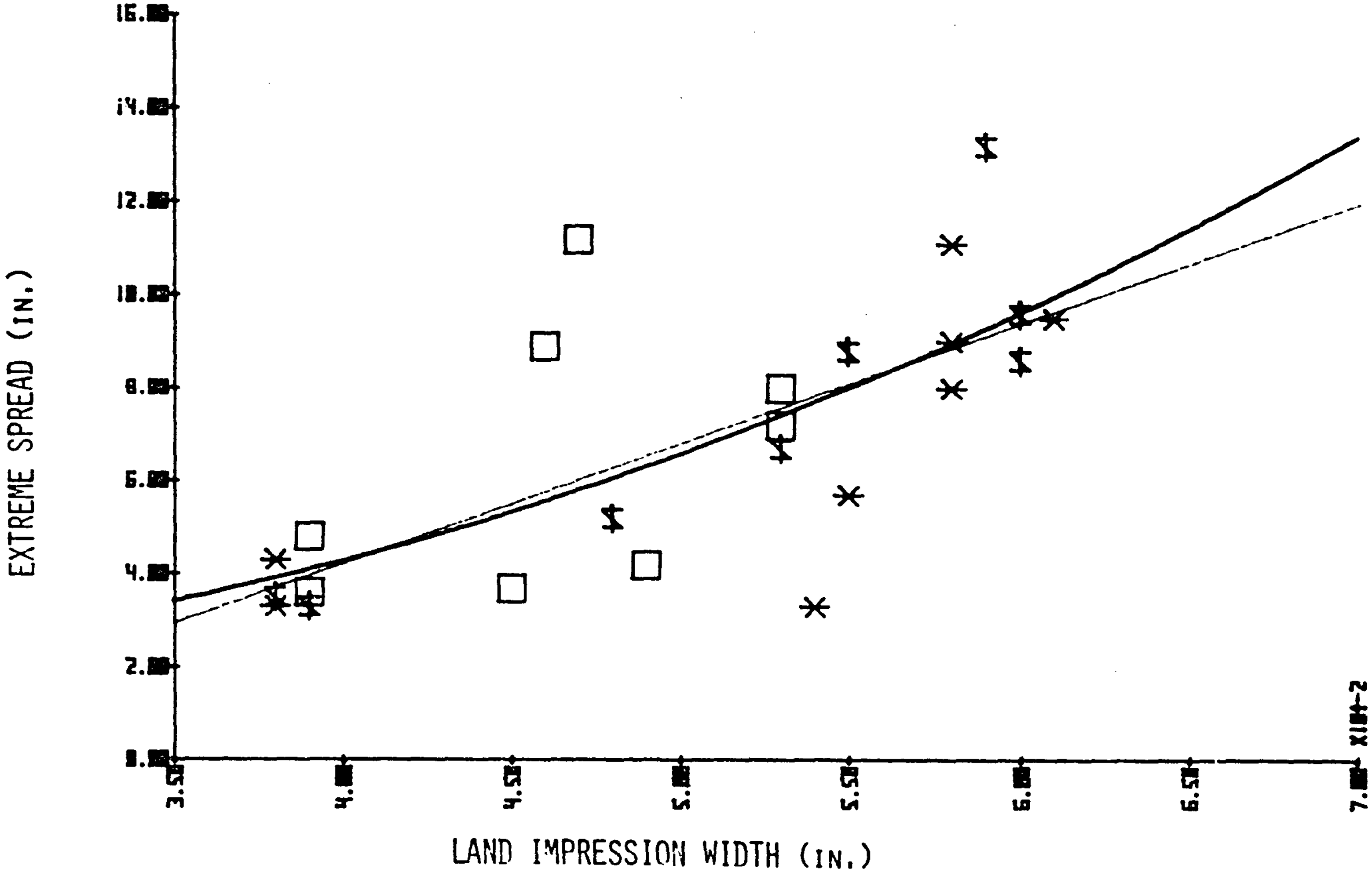
GRAPH 9

100 RDS PER MIN, ALL PROCESSES , BALL AMMO



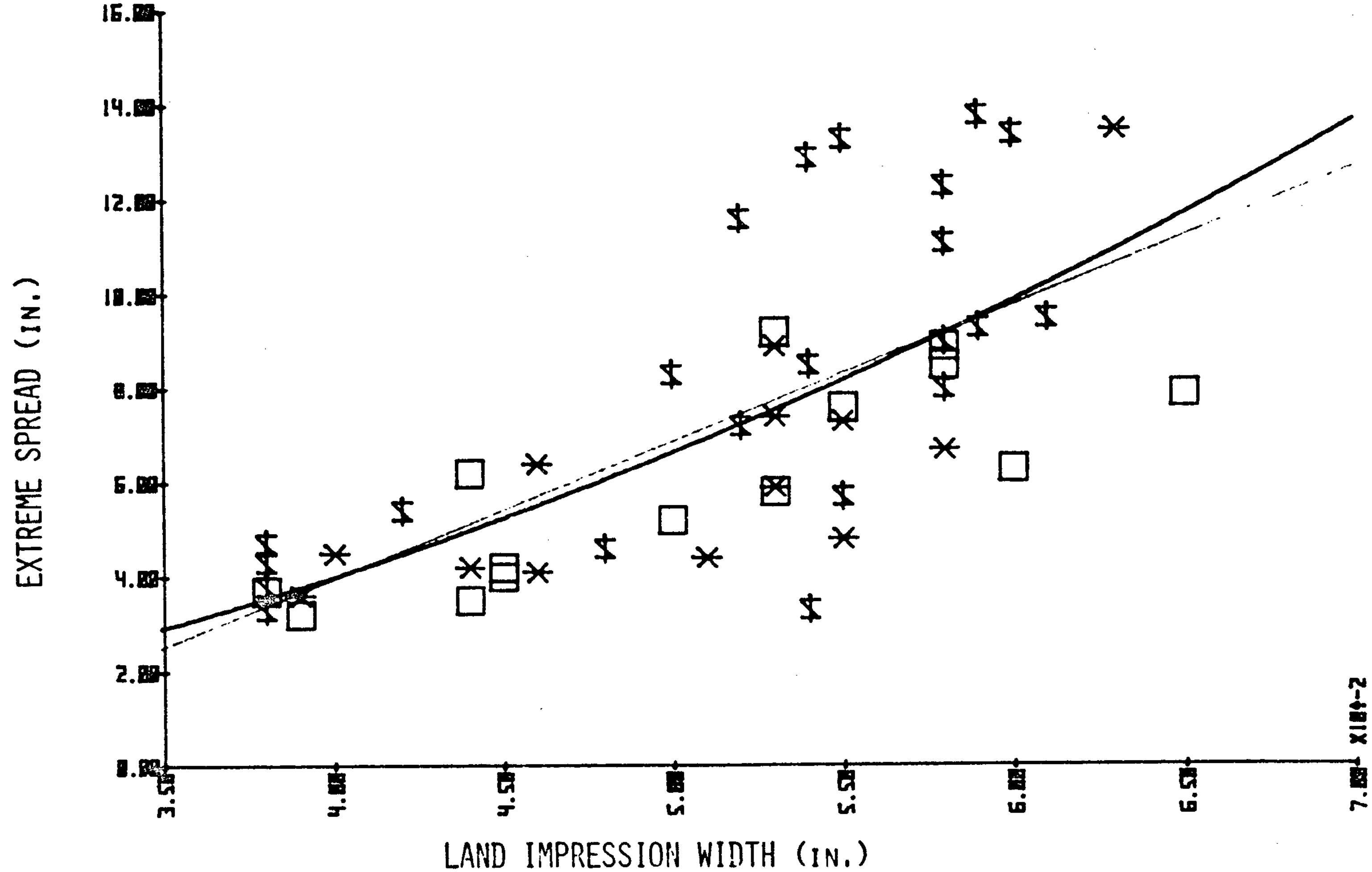
GRAPH 10

60 RDS PER MIN, ALL PROCESSES , BALL AMMO



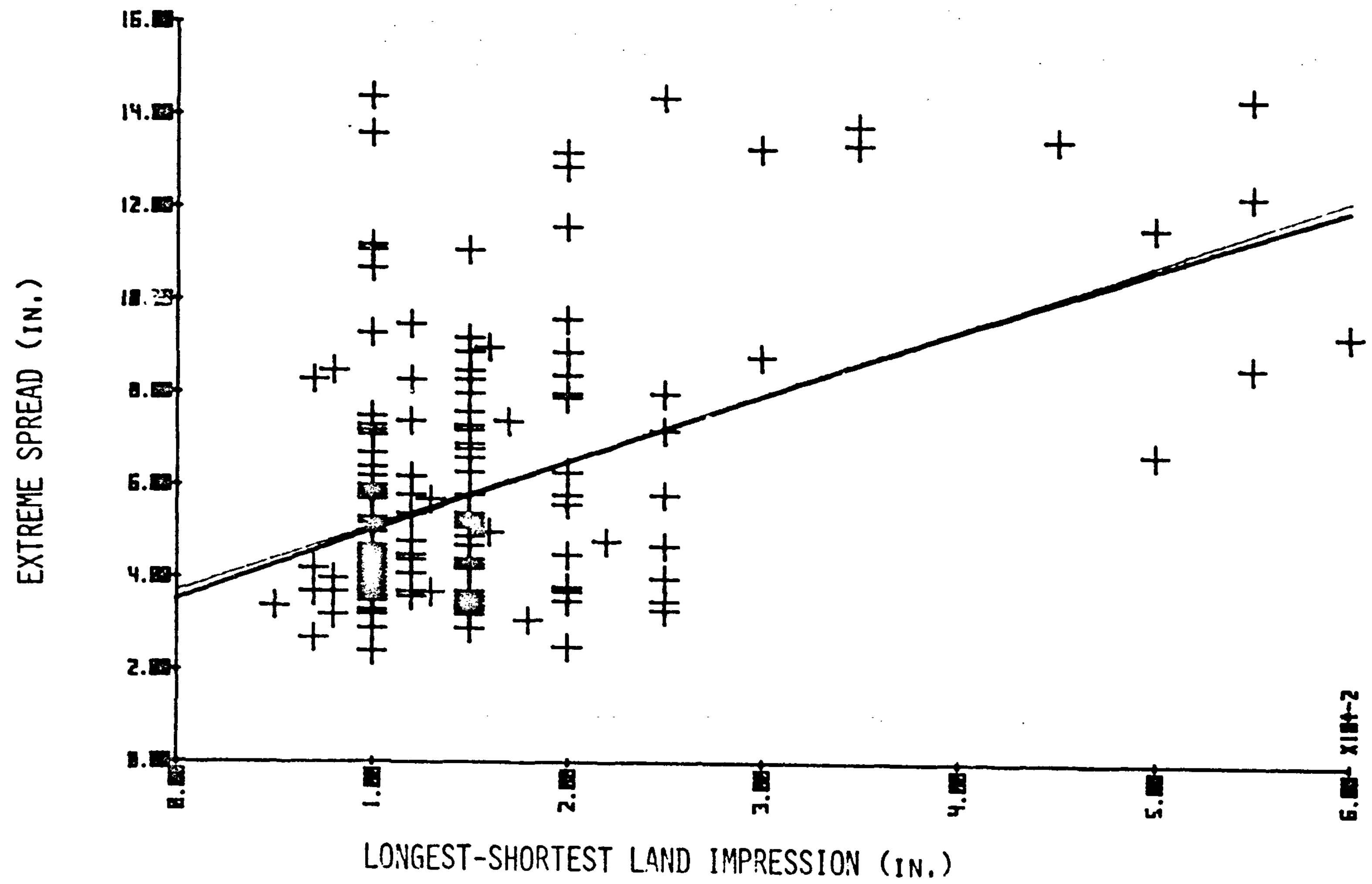
GRAPH 11

20 RDS PER MIN, ALL PROCESSES, , BALL AMMO



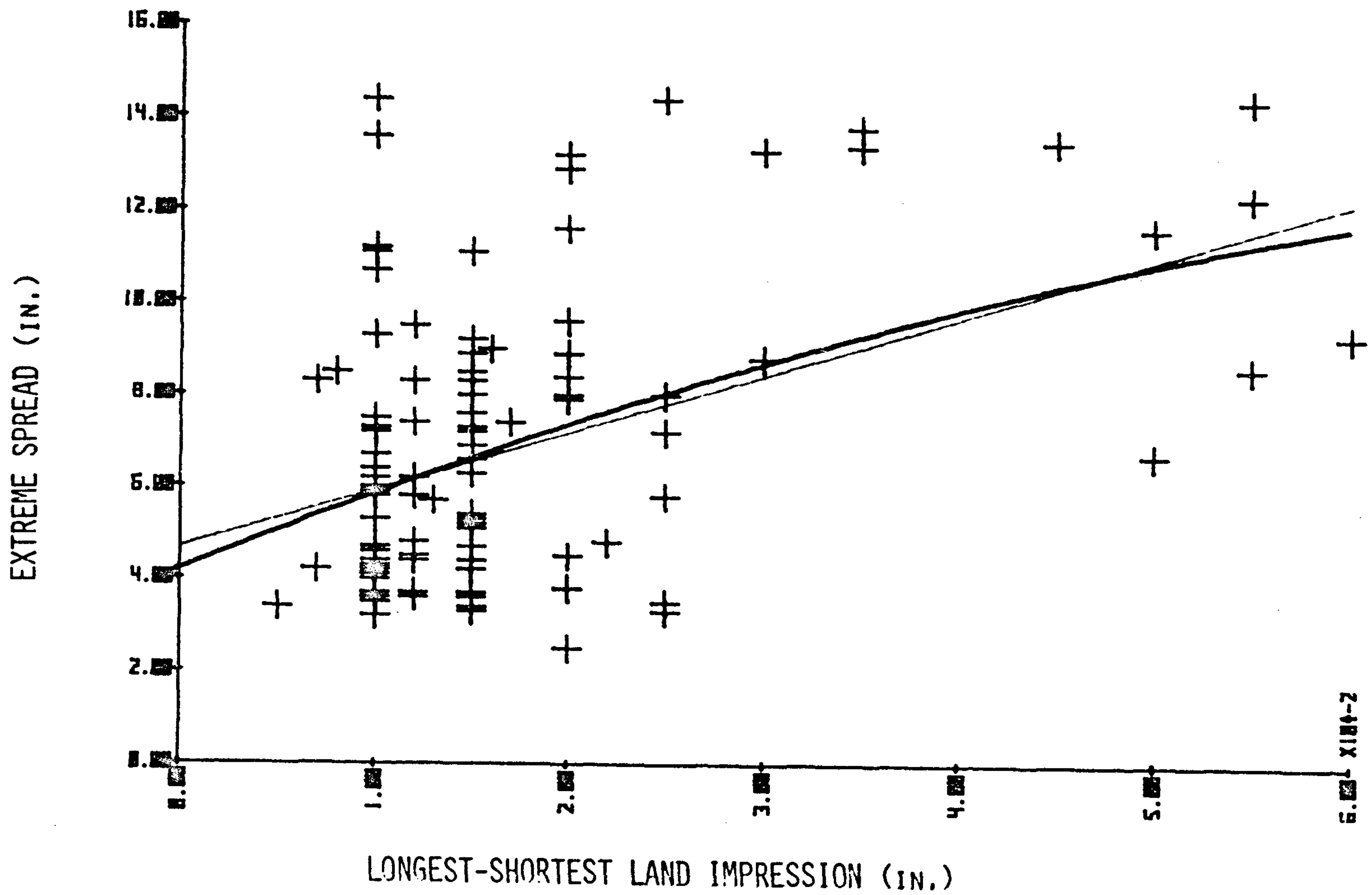
GRAPH 12

ALL RATES, ALL PROCESSES , ALL AMMO



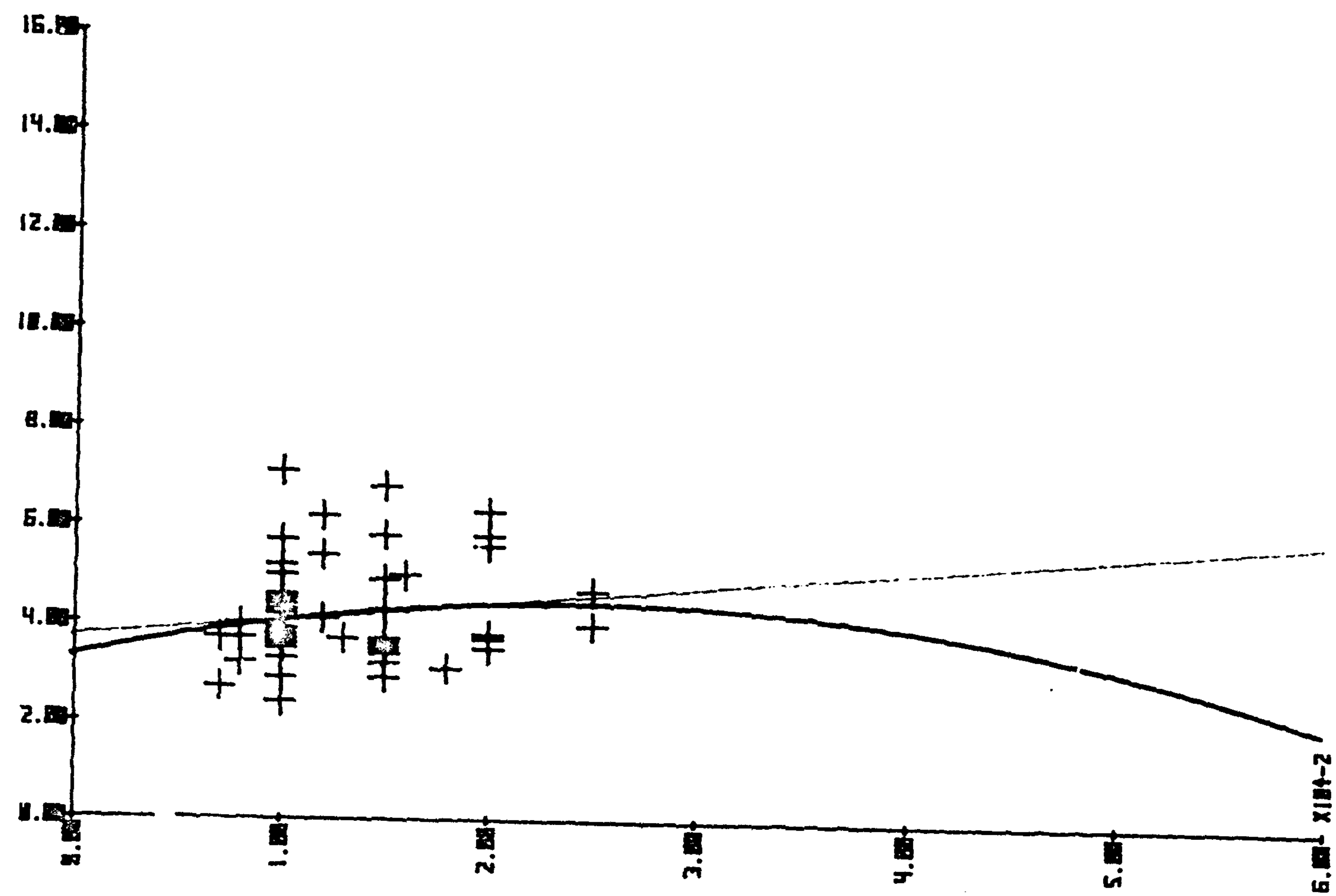
GRAPH 13

ALL RATES, ALL PROCESSES , BALL AMMO



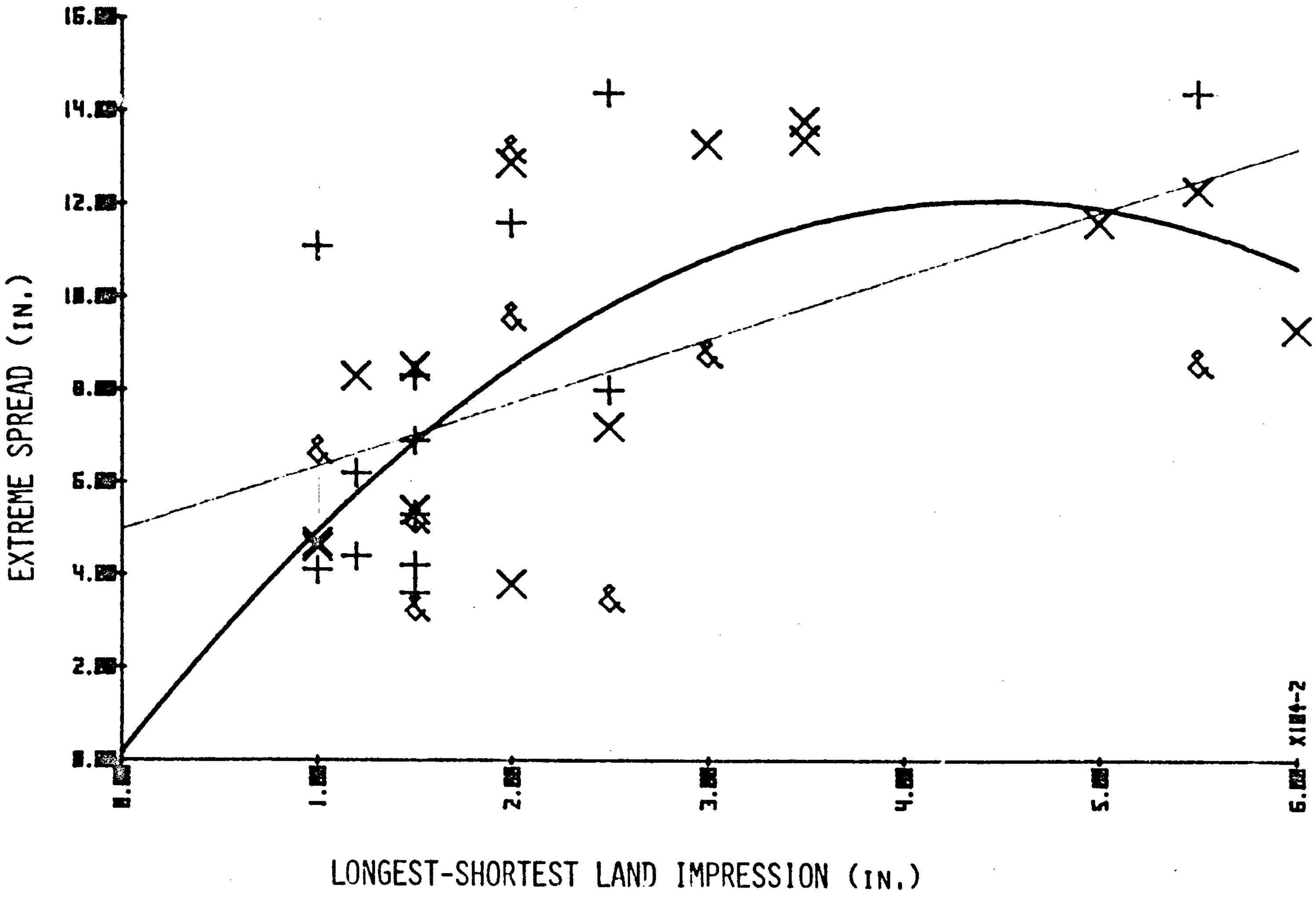
GRAPH 14

ALL RATES, ALL PROCESSES, TRACER AMMO



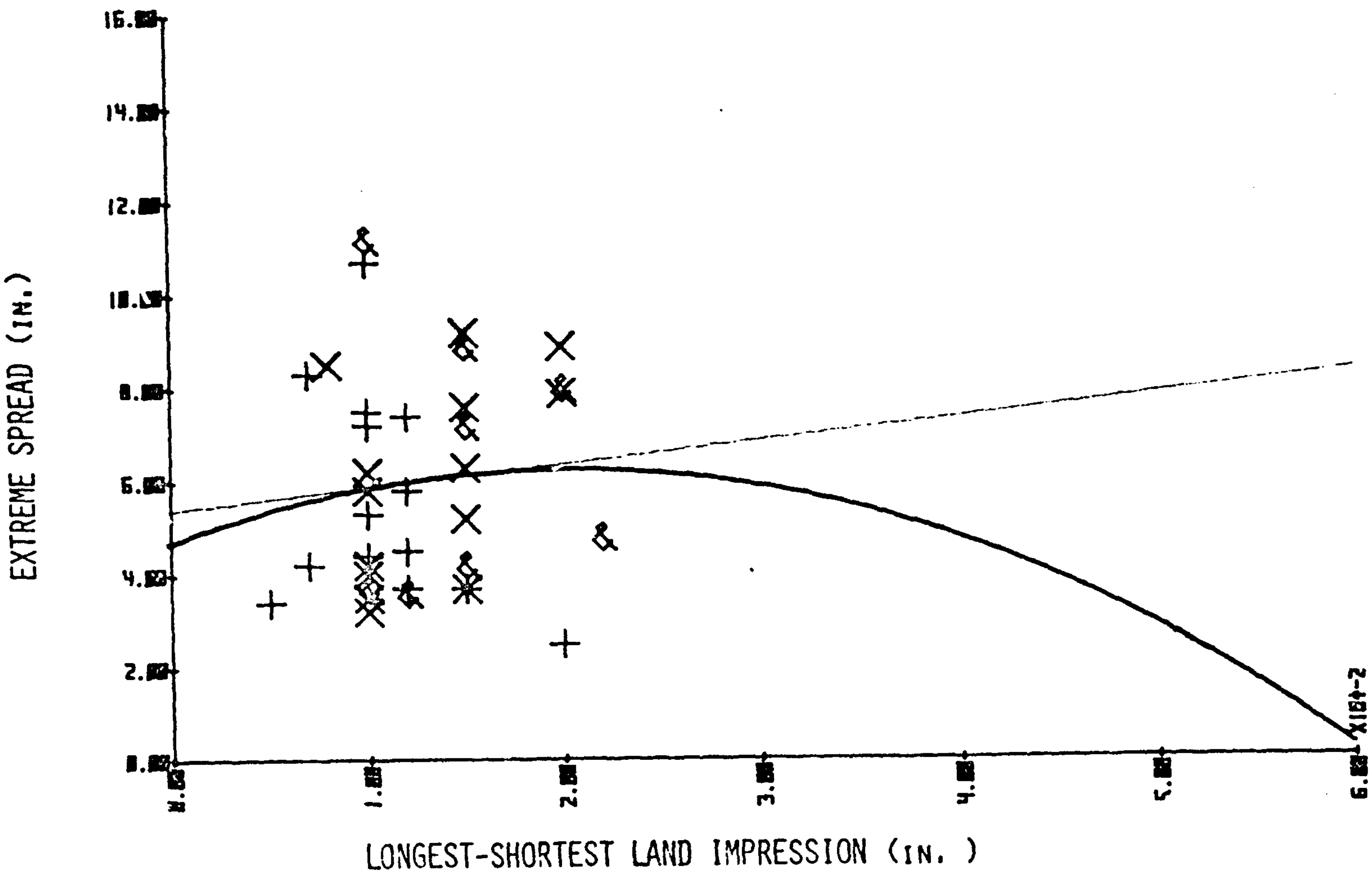
GRAPH 15

ALL RATES, PROCESS A, BALL AMMO



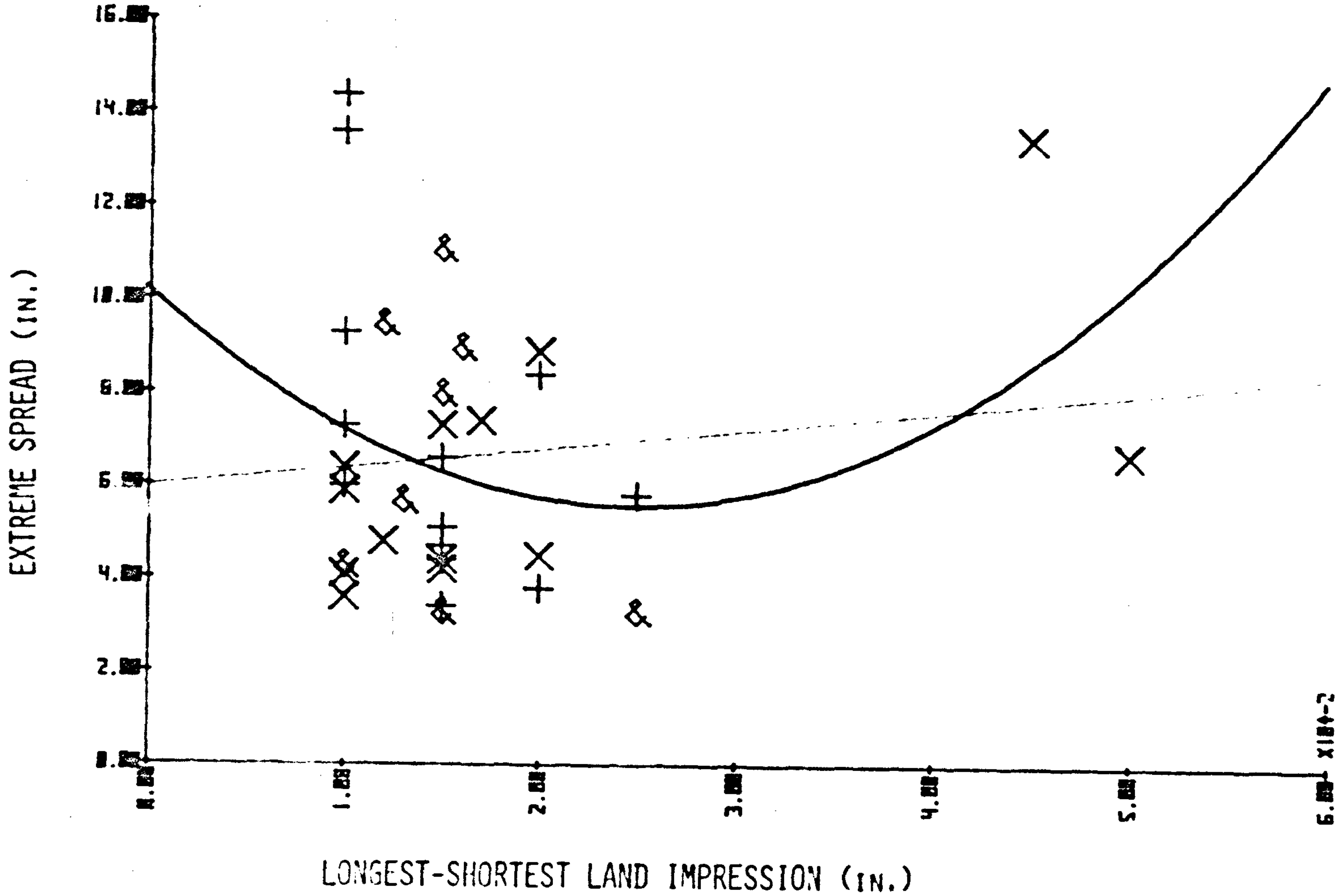
GRAPH 16

ALL RATES,   PROCESS B, BALL AMMO



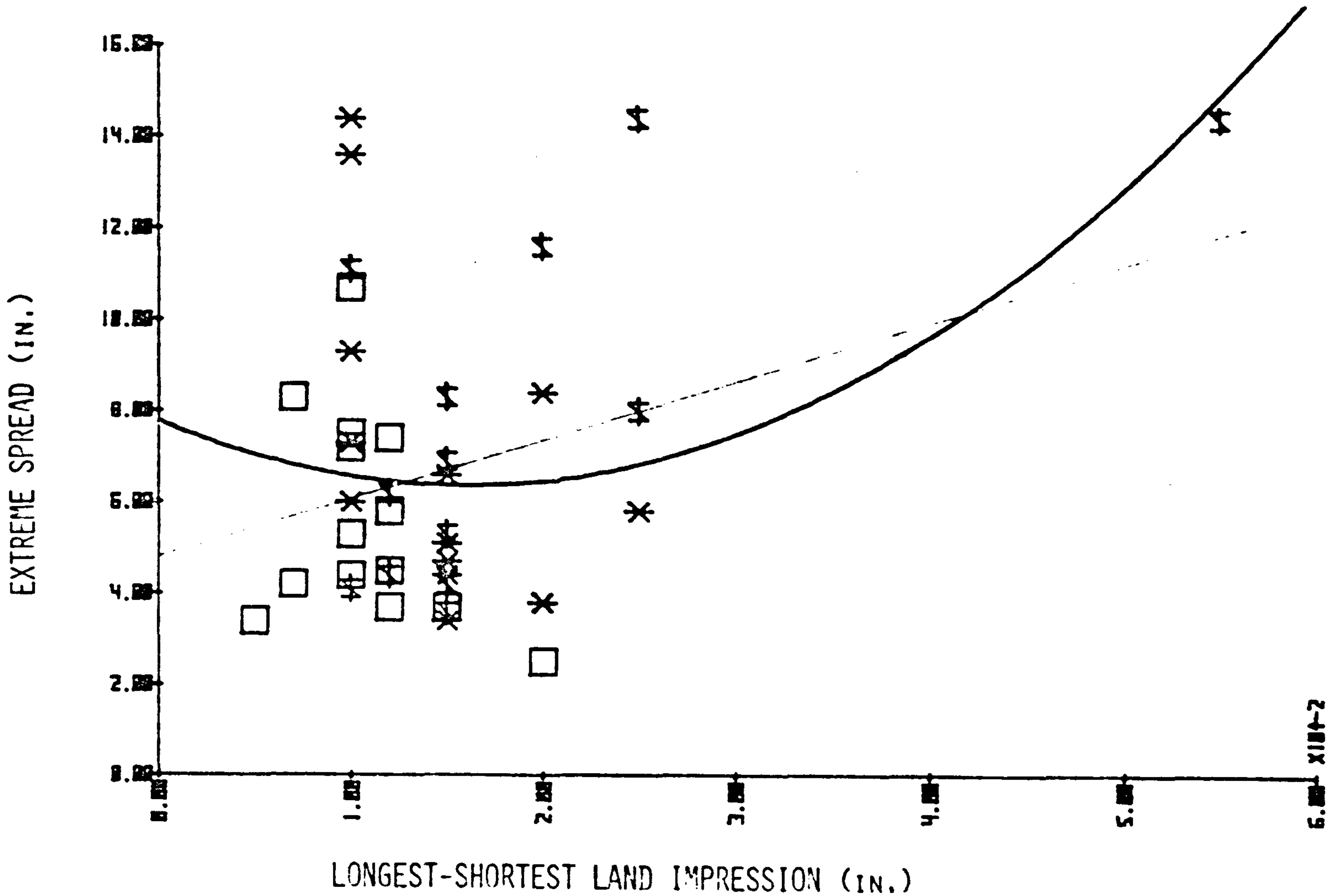
GRAPH 17

ALL RATES, PROCESS C, BALL AMMO



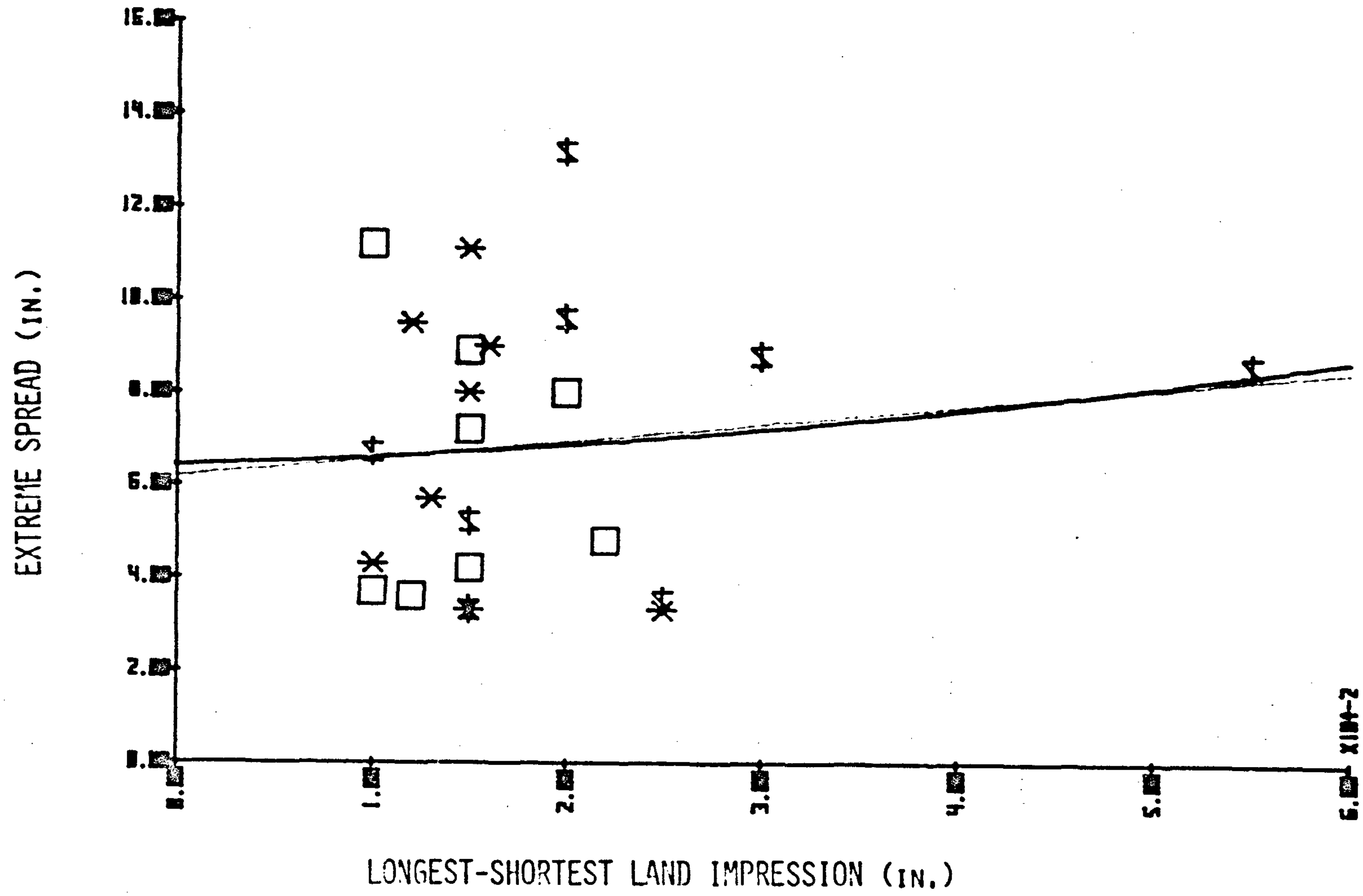
GRAPH 18

100 RDS PER MIN, ALL PROCESSES , BALL AMMO



GRAPH 19

60 RDS PER MIN, ALL PROCESSES , BALL AMMO



GRAPH 20

20 RDS PER MIN, ALL PROCESSES, BALL AMMO